VOL. 4 No. 5 MAY 1939

Philips Technical Review

DEALING WITH TECHNICAL PROBLEMS
RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
N.V. PHILIPS' GLOEILAMPENFABRIEKEN

EDITED BY THE RESEARCH LABORATORY OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN, EINDHOVEN, HOLLAND

AIR-COOLED TRANSMITTING VALVES

by M. van de BEEK.

621.396.615.16.032.42

In transmitting valves with an anode dissipation of more than about 1 kW it is necessary to cool the anode. In the range between 1 and 10 kW air cooling can be used with advantage. While it is true that it is less effective than water cooling, which must be used for higher powers, it nevertheless has the advantage of entailing fewer structural difficulties in connection with the high potential of the anode. In this article the data are discussed which are necessary for the calculation of the functioning of an aircooled radiator; as a practical application of this a discussion is given of the cooler which was developed in order to replace the water cooling of the transmitting valve PA 12/15 by air cooling. (A similar system for other transmitting valves has not yet been worked out).

Introduction

A transmitting valve has the task of converting direct current energy into high-frequency alternating current energy. The technology of transmitting valves has developed along the line of generating greater and greater powers by means of a single transmitting valve. Since the conversion of direct current energy into alternating current energy is always accompanied by a loss of a few per cent [1], a considerable amount of energy is lost in the valve itself, and chiefly in the form of heat at the anode. A smaller amount of heat is developed by the filament and by the grids.

In the original construction of transmitting valves in which the electrode system was placed in a glass bulb, almost all of the heat developed by the anode had to be dissipated in the form of radiation. For a given temperature of the anode the heat radiated is proportional to the surface.

A limit is set to the enlargement of the radiating surface, on the one hand by the dimensions of the glass bulb, which in a practical case cannot exceed a certain value, and on the other hand by the requirements of transmission technology which seeks a compact arrangement of all parts. For short waves it is quite impossible to use transmitting valves of large dimensions because the efficiency of an oscillator falls rapidly when the dimensions of the transmitting valves are greater than for instance several per cent of the wave length.

The practical limit for transmitting valves which must dissipate by radiation the heat developed lies at a total dissipation of about 1 250 W. This may, for example, consist of an anode dissipation of 1 000 W and a filament dissipation of 250 W. If the dissipation of the screen grid must also be taken into acount the permissible anode dissipation is even lower than 1 000 W.

For very high powers the entirely glass transmitting valve has been superseded by one in which the anode is constructed in the form of a metal can closed by a glass top into which the fastenings and the leads of the other electrodes are sealed. In this construction (see Philips Techn. Rev. **2**, 264, 1937) the anode can be cooled with water so that the power developed can be increased about 20 times with the same size of valve.

The application of water cooling is not, however, always possible, since in many places (on board ship, in high arid regions, etc) the necessary amount of cooling water is not available. Furthermore water cooling is accompanied by various complications, due to the fact that the anode is at a high potential while the cooling-water comes out of the mains at earth potential. A greater potential gradient along the cooling-water line than about 1 kV/m is not permissible, and since with large transmitting valves anode potentials of up to 20 kV are used, the water must be conducted to the valve through long rubber tubes. In connection with these complications the use of water cooling is justified only when very high powers must be generated with a single valve; the smallest water-cooled Philips transmitting valve (type TA 10/5 000) is constructed for a total dissipation of 8 000 W.

---

[1] The efficiency of a transmitting valve may amount to from 30 to 80 per cent according to the adjustment; see in this connection J. P. Heyboer, Five-electrode transmitting valves, Philips techn. Rev. **2**, 257, 1937.

For powers between 1 250 and 8 000 W, where neither of the methods of cooling discussed until now is entirely satisfactory, a useful intermediate system is that of forced air cooling. While it is true that the transfer of heat between metal and air is less rapid than from metal to water, it is on the other hand also true that an installation for air cooling is considerably simpler and cheaper than a water-cooling installation, and at the same time it requires less maintenance.

In this article we shall calculate the cooling effect of a current of air, and then give a description of an actual installation for forced air cooling of a transmitting valve.

Dissipation of heat by air cooling

In the cooling systems dealt with in this article, currents of air are used which have a high velocity but a relatively small excess pressure (not more than 1 per cent of the pressure of the outside atmosphere). We may therefore assume that the heating takes place at constant pressure and that we are concerned with the specific heat at constant pressure, which amounts practically to 1 kilojoule/kg [2]).

If we wish to dissipate a power of p kW by means of an air current of q kg/min, then the following relation holds for the increase of temperature of the air $t_2 - t_1 = \Delta t$:

$$q \cdot \Delta t = 60\ p$$

and thus

$$q = \frac{60\,p}{\Delta t} \quad \cdots\cdots\cdots \quad (1)$$

In *fig. 1a* the relation between the electrical energy to be dissipated p and the weight of air q necessary per minute is plotted for different values of Δt. In order to calculate the volume of air to be used, its weight must be divided by the specific weight γ of air at the temperature t_1 at which it is admitted. The relation between weight and volume for a pressure of 76 cm Hg is given in fig. 1b and can also easily be calculated by means of the table below.

t_1 =	0°	10°	20°	30°	40°
γ =	1.28	1.24	1.20	1.16	1.12 kg/cu.m.

From figs. 1a and b we may now read off directly how many cubic metres of air are needed per minute to dissipate a given amount of energy at a given admission temperature of the air and with a given temperature increase of the air.

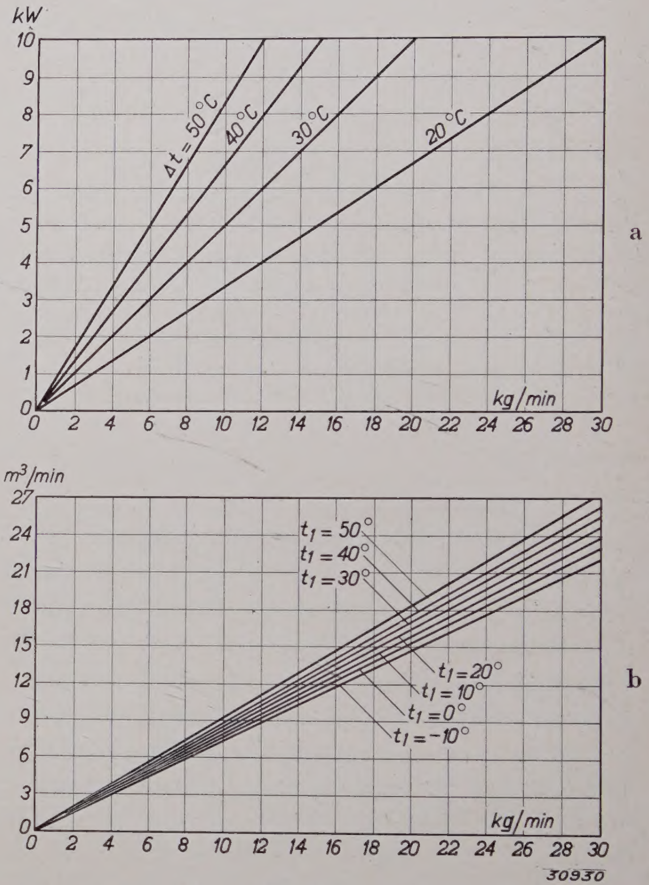


Fig. 1. a) The energy (kW) dissipated by a cooling current of air as a function of the quantity of air (kg/min) with different increases of temperature Δt of the air in the cooler.
b) Relation between volume (cu.m) and weight (kg) of air at different temperatures (°C).

Heat transfer from metal to air

When air of a certain temperature passes over a metal surface with a higher temperature, a certain transfer of heat will take place from the metal to the air. Since heat dissipation by radiation plays no part at the temperatures in question, we are only concerned with heat conduction by the air.

This transfer of heat, taken per unit of time, is proportional to the difference in temperature and to the size of the surface of contact. At the same time the heat transfer must also depend upon the nature of the contact, whereby the condition of the surface and the velocity of the air along the surface are important factors. The influence of these last two factors is generally taken into account by an empirical coefficient of heat transfer α.

---

[2]) The specific heat of air is C_p = 0.241 kg.cal/kg, while 1 kilojoule = 0.239 kg. cal.

In this way we arrive at the following expression for the total heat transfer per unit of time:

$$p = \alpha F (t - \delta), \quad . \; . \; . \; . \; . \; . \; . \quad (2)$$

where α = coefficient of heat transfer (see later),
F = surface of contact of the air,
t = temperature of the metal surface,
δ = average temperature of the air ($\delta = t_1 + {}^1/_2\, \Delta t$).

It must be pointed out that this expression holds only for a state of equilibrium in which the temperatures are constant and the heat dissipated corresponds to the dissipation p of the transmitting valve.

When it is taken into account that according to equation (1)

$$\delta = t_1 + {}^1/_2\, \Delta t = t_1 + {}^1/_2\, 60\, p/q,$$

δ can be eliminated from equation (2) and one obtains:

$$p\,(1 + 30\, \alpha F/q) = \alpha F (t - t_1) \quad . \; . \; . \quad (3)$$

For a given cooler, through which a known amount of air of a given initial temperature is conducted, equation (3) indicates the maximum amount of energy which can be dissipated, if the outer wall of the anode may not exceed a certain temperature t.

We shall now consider in more detail the coefficient of heat transfer α. As was stated above, α depends upon the nature of the surface of contact and the speed at which the air passes over the surface. The following values of α are given in the literature for different values of the velocity w of the air:

Nature of the surface	$w < 5$ m/sec	$w > 5$ m/sec
Polished	$5.58+3.88$ W (watts/m^2)	$7.12\, w^{0.78}$ (watts/m^2)
Rolled	$5.82+3{,}83$ W (,,)	$7.14\, w^{0.78}$ (,,)
Roughened	$6.17+3.80$ W (,,)	$7.17\, w^{0.78}$ (,,)

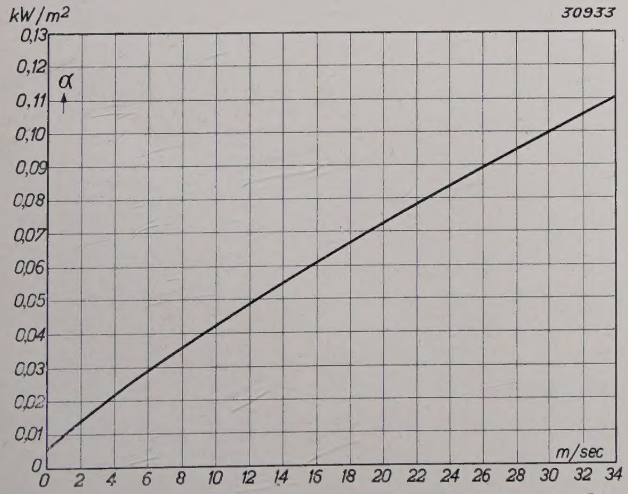


Fig. 2. Coefficient of heat transfer in kW/sq.m from a plate with rolled surface to air, as a function of the velocity of the air.

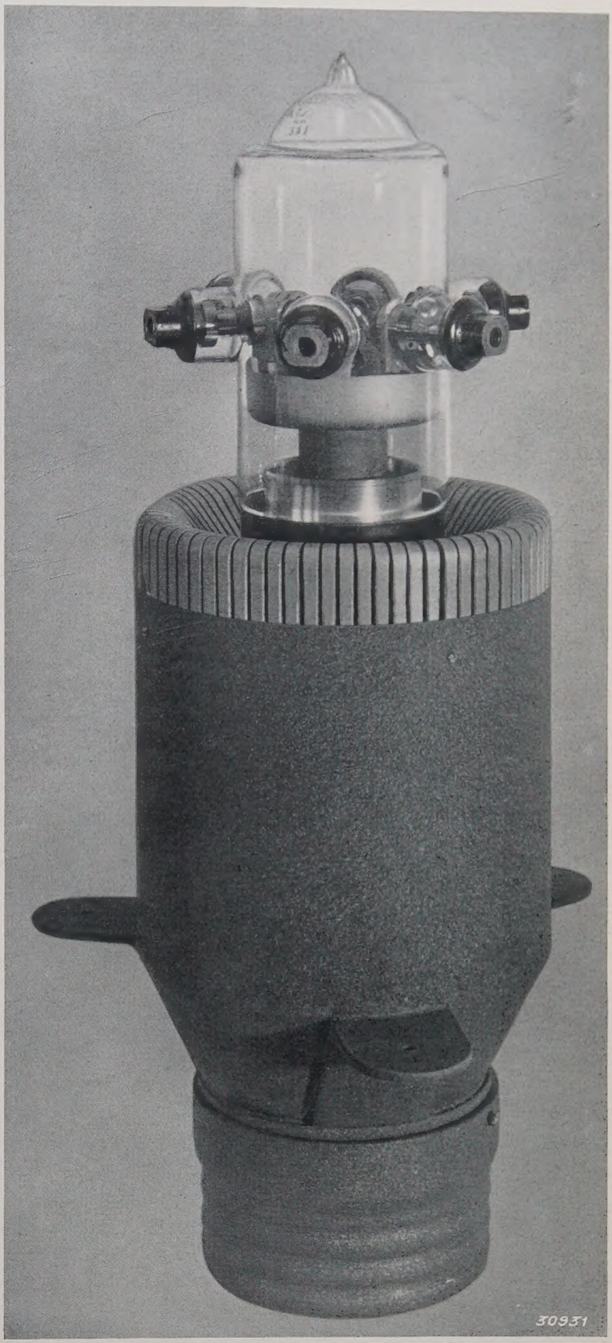


Fig. 3. The transmitting valve PA 12/15 surrounded by a cooler through which a current of air is sent from bottom to top.

From the above values it may be seen that the

---

[3] H. Gröber, Einführung in die Lehre der Wärmeübertragung 1920, see also Hütte, vol. 1, p. 457, 1925. The values of α are given by Gröber in kg. cal./sq.m. hr, but have here been recalculated to watt/sq.m (1 W/sq.m = 0.86 kg. cal/sq. m. hr.)

nature of the surface for velocities greater than 5 m/sec has only a very slight effect on the capacity of dissipation. In *fig. 2* the coefficient a is plotted for a rolled surface as a function of the velocity of air w.

Calculation of a practical example

On the basis of the foregoing discussion we shall now calculate how much energy can be dissipated from a Philips transmitting valve with air cooling such as is shown in *fig. 3*. The valve is the transmitting valve PA 12/15 [4]), which is ordinarily cooled with water, and which in that case can dissipate 12 kW. The surrounding cylinder for water cooling is now, however, replaced by a radiator with cooling fins for forced air cooling. This cooler is shown separately in *fig. 4*.

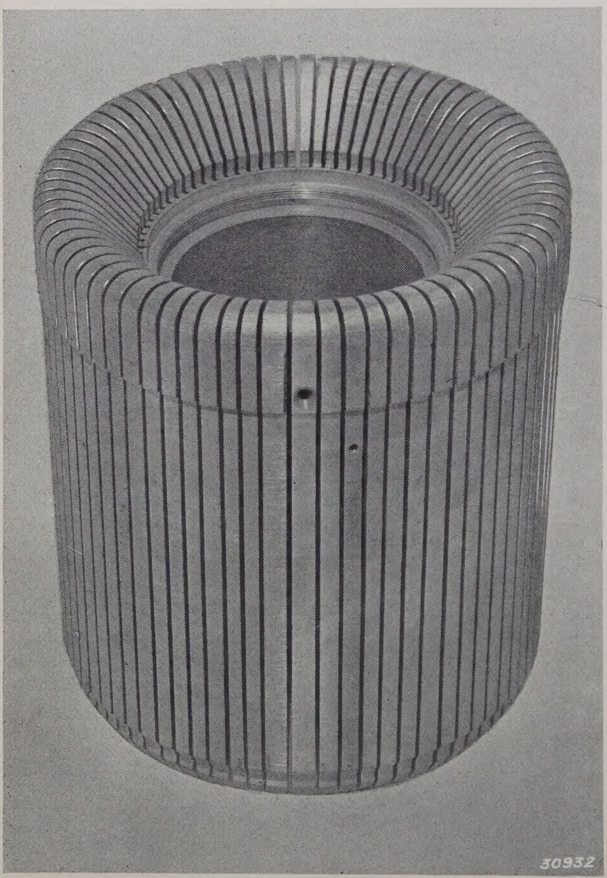


Fig. 4. Ribbed construction of the radiator.

Figs. 3 and 4 show clearly the construction of the whole. The cooling air is conducted upwards from below through the slot of the cooler and flows freely out at the top. It hereby passes over the glass top through which the connections of the cathodes and grids are lead out.

This is a point which illustrates clearly the advantage of air cooling. The glass bulb of a transmitting valve is heated by high frequency fields which cause dielectric losses in the glass, especially on short waves. The softening point of the glass may even by reached due to this cause. Furthermore on short waves a heating up of the connections occurs due to the high capacitative currents which are a consequence of the capacities between the electrodes. Too great a difference in temperature between the connecting wires and the glass would lead to rupture of the joint between metal and glass. One or the other of these facts often sets a limit to the shortness of the waves on which a given transmitting valve can be used; in order to reach shorter waves it would be necessary to introduce special cooling for the sealing-in spots, which would present great technical difficulties because of the fact that the sealing-in spots are at a different potential than the anode.

In air cooling, on the other hand, no separate cooling is necessary because the air flowing out freely still has sufficient cooling action. The cooling is of course much less intense than that by a radiator, and the temperature of the sealing-in spots will be somewhat higher than the temperature of the escaping air.

The radiator consists of 76 ribs, between which are slits for the stream of air. Each slot is 2 mm wide, 47.5 mm deep and 220 mm long. The cross section area of the slot is thus 0.95 sq.cm and the total cross section for the air current is $76 \times 0.95 = 72$ sq.cm.

A current of air of 14 cu.m/min. is now sent through this cooler. The average velocity of the air is then $\frac{14}{60 \times 0.0072} = 32.4$ m/sec. Because of this high air velocity we are certainly concerned with turbulent and not with laminary air flow. It may therefore be assumed that the air also flows along the walls of the cooler with this velocity (while with laminary flow the velocity would decrease gradually toward the wall). From fig. 2 we find for an air velocity of 32.4 m/sec a corresponding value $a = 0.107$ kW/sq.m. The wall surface of the cooler is 210 sq.cm. per slot, thus in all $F = 76.210$ sq. cm $= 1.6$ sq.m. If we now assume a temperature of the air $t_1 = 20°$C, the specific weight of the air is 1.2 kg/cu.m and the weight of the air used is thus $14 \times 1.2 = 16.8$ kg/min. If moreover we let the permissible temperature of the cooler t equal 106°C, then we can determine the maximum energy to be dissipated according to equation (3):

$$p = \frac{a\,F\,(t - t_1)}{1 + 30\,a\,F/q}\,.$$

With the following numerical values of the quantities:

---

[4]) This transmitting valve has been mentioned repeatedly in Philips techn. Rev. and is shown in vol. 2, page 264, 1937.

$$\begin{aligned} a &= 0.107 \text{ kW/sq.m } ^\circ\text{C}, \\ F &= 1.6 \text{ sq.m.}, \\ t_1 &= 20^\circ \text{ C}, \\ t &= 106^\circ \text{ C}, \\ q &= 16.8 \text{ kg./min}, \end{aligned}$$

we calculate $p = \dfrac{14.7}{1.306} = 11.25$ kW.

From equation (1) we calculate the increase in the air temperature and find

$$\Delta t = \frac{60\,p}{q} = \frac{60 \cdot 11.2}{16.8} = 40^\circ\text{C},$$

and therefore $t_2 = t_1 + \Delta t = 60^\circ$ C.

"Internal" temperature loss

Until now the calculations have been carried out as if the metal part of the cooler were at a uniform temperature. Actually the temperature at the outer circumference of the cooler is lower at the base of the ribs because the conduction of heat by the ribs is toward the outside. Moreover, there is also a certain temperature decrease from the inside of the anode toward the base of the ribs, *i.e.* in the anode itself, in the connection anode-cooler and in the inner cylinder of the cooler.

If we nevertheless wish to apply equation (3), t must be considered as an average temperature of the surface of the radiator; t must therefore be chosen lower than the maximum temperature permissible on the inner wall of the anode. The internal fall of temperature increases with the energy dissipated. This decreases still further the dissipation permissible, and even with the most intense cooling it could not exceed a definite limit. By using a material for the cooler which conducts heat well, the internall fall of temperature can, however, be kept quite low. In the construction here chosen the heat current flows through a cross section of 670 sq.cm on an average. The length of the lines of flow is 3 cm on an average, while the heat conduction in this way for a temperature gradient of 1° C/m is 110 kg.cal. per sq.m. per hr. If these values are used it is found that the temperature drop from the inner wall of the anode to halfway to the extremities of the cooling fins is not more than 3.5° C per kW. If we let the temperature of the anode be T, the average temperature of the cooler is

$$t = T - 3.5\,p$$

and by filling in this value of t in equation (3) we obtain

$$p\,(1 + 30\,a\,F/q + 3.5\,a\,F) = a\,F\,(T - t_1)\,. \quad (4)$$

With the help of this equation it is possible to calculate the maximum energy p to be dissipated as a function of the current of air q and the temperature of admission t_1, as has already been done above by means of equation (3). It is, however, no longer necessary to make a quite arbitrary assumption about the maximum permissible temperature t halfway to the extremities of the fins, but a limit may be indicated for the temperature T at the inner side of the anode whose permissible value can be better estimated, because it is actually the anode temperature to which a limit must be set. If the value 145° C is chosen for this, which is on the safe side, then at $t_1 = 20^\circ$ C and $q = 16.8$ kg/min. a value of t is found equal to 106° C. In this way the permissible value of t used above was derived.

If the same calculation is carried out for a number of other admission temperatures and amounts of air per minute, values are found for the maximum permissible power at an anode temperature of 145° C which can be read off in *fig. 5*.

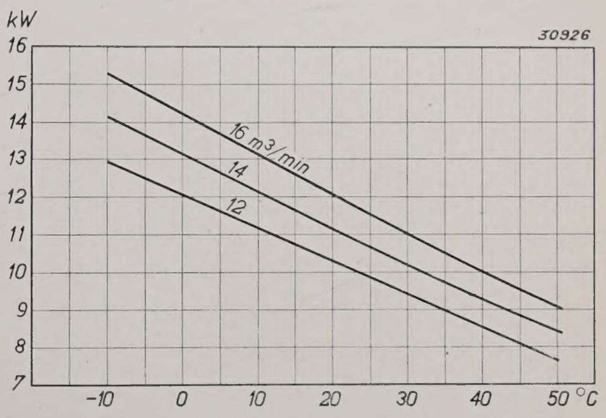


Fig. 5. The energy removed by the cooler of the transmitting valve PA 12/15 as a function of the admission temperature of the air, when the flow of air is 12, 14 and 16 cu.m/min, respectively.

Several points in the construction of the cooling system

The air resistance of the cooler

In order to transfer as much heat as possible to a given amount of air it is desirable to make the surface of contact F for the air as large as possible with a given cross section of the air channel (see equation (2)); it is for this reason that very flat narrow cross sections are the most advantageous. Furthermore, in order to make the coefficient a of heat transfer large, a fairly high air velocity is required. By taking these two points into account, however, a high resistance of the air current is obtained.

In *fig. 6* the difference in pressure (mm water), occurring in the cooler is plotted as a funtion of the velocity of flow (cu.m of air per min). It is found that the excess pressure necessary increases almost with the square of the air velocity which means that the energy necessary for cooling is almost proportional to the third power of the air velocity. With an air current of 14 cu. m/ min. an excess pressure of 115 mm water occurs; from this it follows that an energy of 264 watts is supplied to the air current [5]).

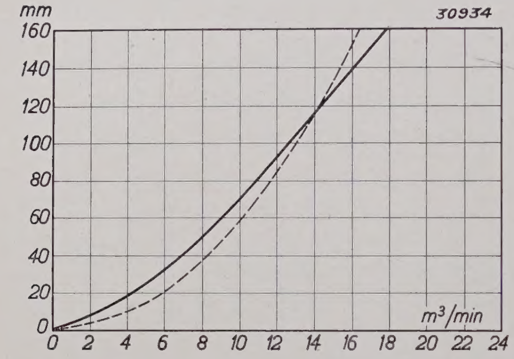


Fig. 6. The difference in pressure (mm of water) which occurs in the slits of the cooler as a function of the magnitude of the air current (cu.m/min). For the sake of comparison a quadratic curve has been indicated by a dotted line.

The fan

The air current is obtained by means of an electrically driven fan. The first requirement made of the fan is that it be able to deliver the desired volume of air at the corresponding pressure. If N is the energy supplied to the air, η_1 the efficiency of the fan and η_2 the efficiency of the electromotor, the necessary electric energy is

$$W = \frac{N}{\eta_1 \cdot \eta_2} .$$

The efficiency η_1 of the fan in a suitable size is about 50 per cent, while the electromotor (a three-phase induction motor) may have in this case an efficiency of 90 per cent. With these values of the efficiencies one calculates for an air current of 14 cu.m./min. (N = 264 watts), that the motor must be able to deliver an energy W of 528 watts, and takes up 587 watts from the mains for this purpose.

Since several extra losses must be taken into account, such as the pressure loss in the air supply line from the fan to the cooler, it is desirable to use a somewhat stronger motor. In our case a motor of nominally 0.8 h.p. is used, which, when loaded by the fan to which the cooler is connected, takes up just 600 watts from the mains.

A second requirement made of the combination of fan and cooler is the absence of noise. Two points are important in this connection; in the first place an aerodynamically good construction, in the second place as low a number of revolutions per minute as possible. The number of revolutions may not, however, be too low, because with a given air current the diameter of the fan must increase in the same ratio as the number of revolutions decreases. In our case an asynchronous motor with two pairs of poles was used, which on a main of 50 c/s has nominally a speed of 1 500 r.p.m. and in use about 1 430 r.p.m.

The connection between the fan and the cooler must still be considered. It must be air tight and at the same time possess a high electrical insulation, since the fan is at earth potential while the cooler is under high tension. A double natural silk "tube" about 35 cm long, which can easily withstand a high frequency voltage of about 7 kv_{max} at a frequency of 50 megacycles/sec, proves very satisfactory.

Conclusion: When is it possible to replace water cooling by air cooling?

In order to judge whether the water cooling can be replaced by air cooling in the case of the water-cooled transmitting valve PA 12/15 when used in a certain adjustment, it is only necessary to add the heating current energy, the screen grid dissipation and the anode dissipation. With the help of fig. 5 it can now be read off whether with the admission temperature of the air available this total amount of energy can be dissipated without requiring too high an air velocity. The velocity will not be chosen greater than 35 to 38 m/sec (18 to 20 cu. m/min) because the driving power and the noise increase very strongly with the air velocity.

As for the anode dissipation, one must not calculate with the carrier-wave adjustment but with 100 per cent modulation. In class B arrangement the dissipation with 100 per cent modulation is for instance 10 per cent, and with anode modulation about 50 per cent higher than with the carrier-wave adjustment.

It is also advisable to use a somewhat larger amount of air than is strictly necessary according to the calculations, in order to run no risks during a temporary sudden increase in the temperature of the outside air.

In order to give an idea of the structural simplicity of the whole combination of a transmitter

---

[5]) The energy supplied is equal to the product of excess pressure (kg/sq.m) and air current (cu.m/sec), thus in our case 26.8 kg.m/sec = 26.8 × 9.81 watts.

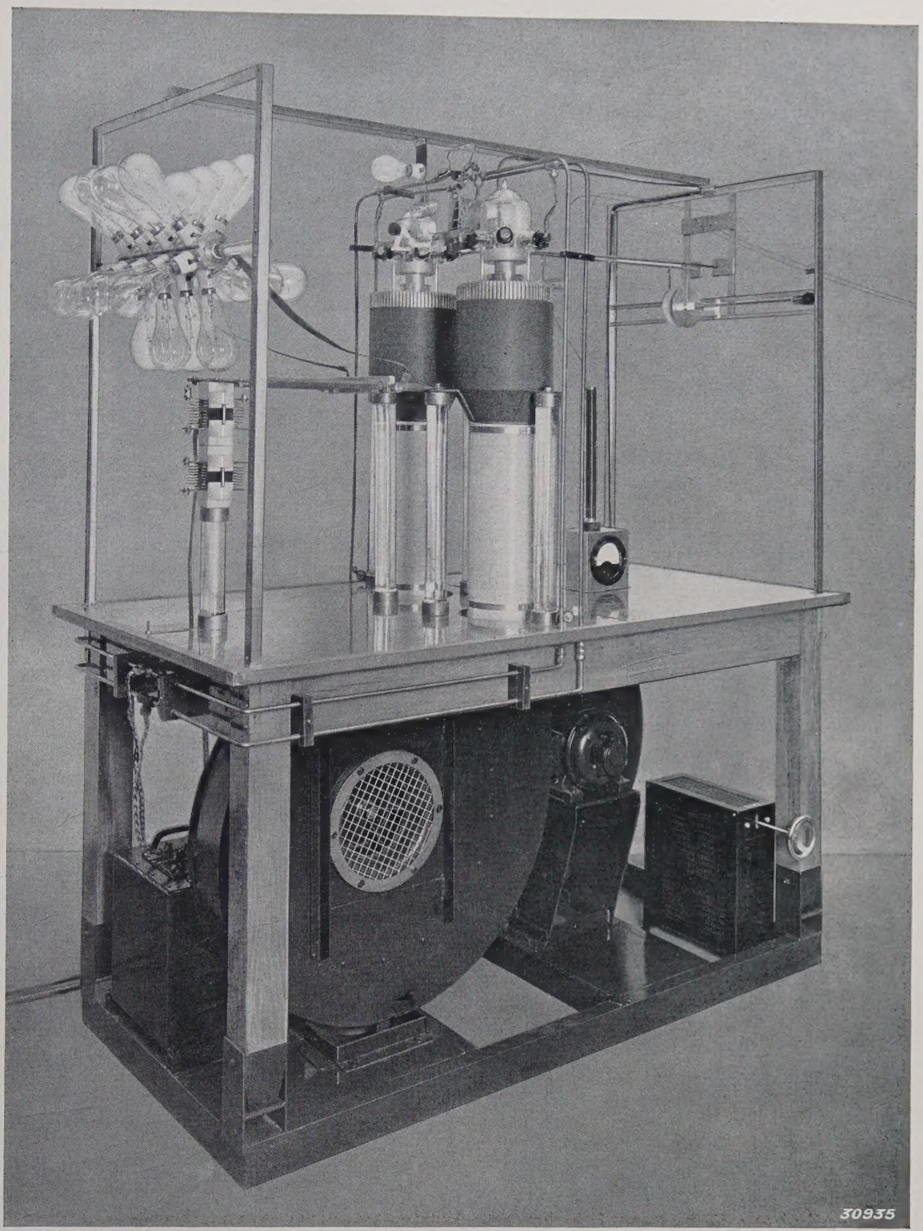


Fig. 7. Laboratory transmitter with two air-cooled transmitting valves type PA 12/15 in push-pull connection. Wave length 6 m, power delivered 6 kW. The carbon filament lamps, upper left, form an artificial aerial to which the power is supplied.

with air-cooled valves, *fig. 7* gives a view of a laboratory transmitter with two air-cooled transmitting valves, type PA 12/15 in push-pull connection. This final stage works on a wave length of 6 m and easily delivers 6 kW to the aerial with an excitation power of about 500 W. The anode dissipation is also 6 kW.

Compared to water cooling with the inevitable tube drums for dealing with the high tension, inlet and outlet connections for the water, pump for the cooling water, and in some cases pools, air cooling makes possible a considerably simpler construction.

THE MANUFACTURE OF RARE GASES

by H. C. A. HOLLEMAN.

661.93

In this article the method is described by which rare gases, oxygen and nitrogen are obtained from air in the Philips concern. The apparatus for the liquefaction of air and for the rectification of the gas mixtures is described.

Introduction

During the world war when it became more and more difficult to import the argon necessary for filling electric lamps, the Philips concern was compelled to take up the manufacture of the gas itself. The gas liquefaction plant then founded continued to grow steadily even after the war, since it was found to supply so many needs. So many different gases which can all be obtained from liquid air are used in the Philips factories, that for more than one reason it is very important to have the whole manufacture under control, and not to be dependent upon others. It seemed to us that it would be interesting to our readers if we were to give a general description of this part of the industry. Besides argon, which is used for filling electric lamps, the rare gases helium and neon are also used in gas discharge tubes. For glass blowing and in the machine shops large quantities of oxygen are used in order to reach higher combustion temperatures than is possible with air. Liquid oxygen and nitrogen are used on a large scale for cooling purposes and as aids in obtaining a high vacuum. As a protective gas in the working of metal parts for electric lamps and radio valves use is made of a mixture of nitrogen and hydrogen. Nitrogen is also used during the manufacture of electric lamps as washing gas, while it is also used to fill certain special kinds of lamps.

If the amount of air treated is determined for example only by the amount of oxygen required for use, it may not of course be expected that the amounts of the other gases obtained will correspond exactly to the needs for them. Especially in the case of nitrogen large quantities must be allowed to escape unused. In spite of this fact, however, due to the great variety of uses for the gases separated out of air, a more economical operation is possible than if only oxygen for example were taken from the air and the rest allowed to escape. Furthermore the great advantage of a private gas plant is that it is possible to take into account the special requirements of the industry more easily than is the case when the gases are supplied from an outside source. With a private gas plant a saving is also obtained due to the fact that different gases can be piped directly from the rectifying apparatus to the places where they are to be used, so that compression into cylinders for transportation is quite unnecessary.

The separation of air into its components is at present carried out almost exclusively by liquefaction and rectification. Rectification is a kind of fractional distillation which is carried out in a column apparatus such as is also used in the preparation of alcohol and paraffin. Before we deal with the subject of rectification we shall first discuss the liquefaction of gases.

Liquefaction of gases by expansion

Due to the work of **Linde**, **Hampson**, **Claude**, **Heylandt** and others it has been possible to liquefy air on a commercial scale since 1896. The Philips rare gas plant used the method of **Linde** and **Hampson** which is based on the cooling due to expansion of air at a high pressure flowing through a needle valve (S in *fig. 1*) into a container at lower pressure. This so-called **Joule-Thomson** effect is a result of the mutual forces of attraction existing between the molecules (**van der Waals** and **London**), by which the energy content of a gas is not determined exclusively

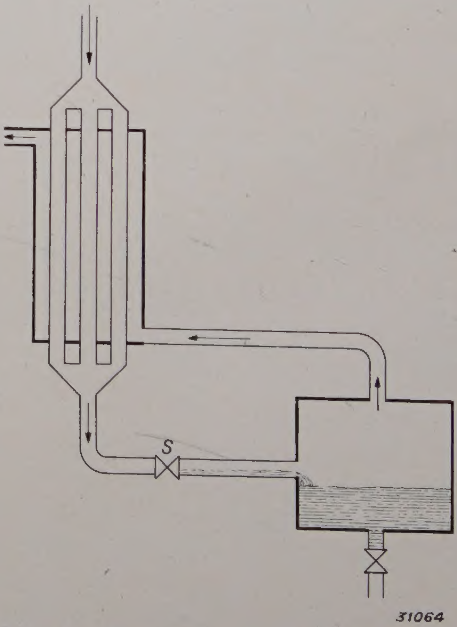


Fig. 1. Diagram of apparatus for the liquefaction of a gas by cooling in an interchanger and expansion through a needle valve S.

by the thermal agitation of the molecules, as in the case of an ideal gas, or in other words by the temperature of the gas, but also depends upon the mean distance between molecules, in other words, on the density of the gas. Upon expansion therefore a non-ideal gas increases its energy content due to the increase in volume, and the energy necessary for this must either be taken from the energy of motion of the molecules, which means that the temperature of the gas falls, or it must be supplied in some other way.

If air at a pressure of for instance 200 atmospheres is allowed to flow through an interchanger as shown diagrammatically in fig. 1, and then allowed to expand through a needle valve *S* and flow back through the interchanger, then with a well-constructed apparatus the air which comes out will not have a very much lower temperature than when it entered. The increase of its energy content due to expansion is obtained by the air by cooling the apparatus itself before the stationary state is reached. When the dew point of the air is finally reached the energy necessary for the expanding air is freed by the liquefaction of part of the air in the apparatus. In the liquefaction of air 90 kg. cal. of heat per kg are obtained, while by the Joule-Thomson effect only about 0.06 kg. cal. per kg of air per atmosphere can be removed, *i.e.* at a pressure of about 200 atmospheres not more than 12 kg. cal. By expansion alone therefore all the expanding air cannot be liquefied. For the separation by rectification, however, it is required that all the air be liquefied in this process. This is accomplished by allowing the air which has already been liquefied to evaporate while the necessary heat of evaporation is taken from the new supply of air, which is thereby liquefied. Such a process is shown diagrammatically in *fig. 2*.

In the working methods shown in fig. 2 between the needle valve *A* and the container *B* practically all the air flowing through is liquid. The liquid collected in the container evaporates continually and takes the necessary heat from the air which flows toward the valve through a cooling coil lying in the container, so that the gas in the coil is already partly liquefied before it reaches the valve. After the expansion at this point it flows to the container *B*, in which the liquid again evaporates. When the purpose is simply to obtain liquid air, there is no fundamental difference between the methods given in figs. 1 and 2, since they produce per unit of time the same amount of usable liquid under similar circumstances. When, however, the liquefaction of air is the preliminary to the separation by rectification, we shall see that the second method has great advantages.

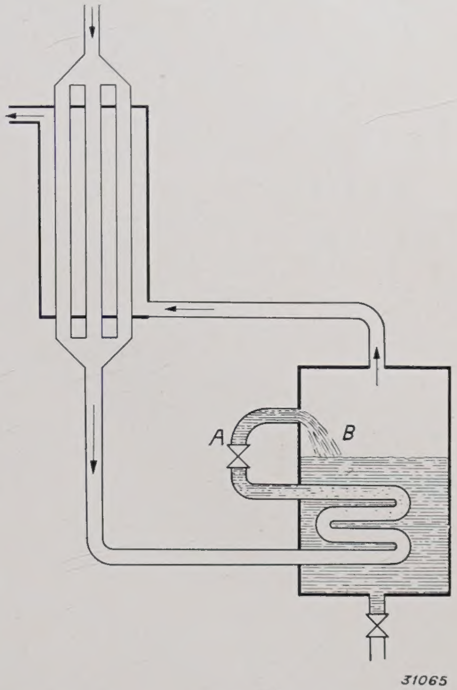


Fig. 2. Diagram of an installation in which a gas is already liquefied in the cooling coil running through the container *B* before it expands through the valve *A*.

In spite of good insulation and an efficient interchanger a certain amount of "cold" is always lost, and in liquefaction for rectification it is really a question of regulating the processes according to fig. 1 or fig. 2 in such a way that in the end no liquid air is obtained, but the supply of liquid in container *B* remains constant. "Cold" is therefore supplied only to compensate for the inevitable losses. By making the pressure at which the air is supplied lower, the production of liquid becomes smaller and merely by lowering the pressure sufficiently, for instance to 50 or 100 atmospheres, it is possible with the apparatus of fig. 1 as well as with that of fig. 2 to keep the quantity of liquid constant. With an apparatus as in fig. 1 only a small part of the air will be liquid after it passes the needle valve, while with the apparatus of fig. 2. all the air flows into the container as a liquid and then evaporates. It is this complete liquefaction and later evaporation which is necessary for rectification.

Rectification

If we have a mixture of substances with only slightly differing boiling points, which we wish to separate by boiling and condensing, rectification is the best method. For smaller amounts this is sometimes done discontinuously in successive batches, but for the separation of air on a large scale technically only a continuous process of rectification may be considered. It is such a method which we shall discuss in the following.

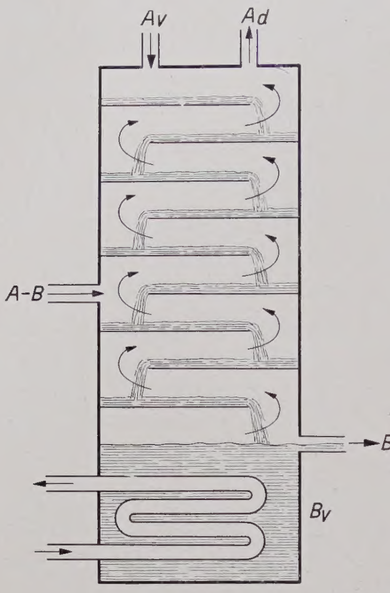


Fig. 3. Diagrammatic representation of the working of a rectification column. The component A of a mixture $A-B$ has a lower boiling point than B. At A_v component A enters the column as a liquid and drips down. At a suitable height the mixture $A-B$ is introduced into the column as a gas or a liquid. At the bottom of the column the liquid B_v collects; the substances B can be drawn off here as a liquid or a gas. The component A escapes at the top of the column as the gas A_d. The circulation in the whole apparatus is maintained because of the fact that the gas flowing through a coil in the liquid container gives off heat which causes the liquid at the bottom of the column to evaporate and rise, while at the top of the column a corresponding amount of liquid is introduced.

Fig. 3 shows the scheme of a continuous rectification. The mixture (air for example) as a liquid or a gas at the boiling point is introduced into a column consisting of many stages at a suitable height depending upon the composition of the mixture. According as the mixture contains more of one of the two components, the point of introduction should be shifted toward the extremity where the component in question is finally obtained. Within the column the liquid and gas flow in opposite directions, liquid downwards and gas upwards, and they are always in intimate contact with each other. The gas leaving the column at the top consists chiefly of the component (A) with the lowest boiling point, while the liquid collected at the bottom of the column consists chiefly of the component (B) with the highest boiling point. By heating the liquid reservoir this mixture rich in B rises again as vapour in the column; since part of the vapour which is formed at the top of the column is also readmitted to the column after having been condensed to a liquid, there are always in the column opposing streams of rising vapour which is becoming richer in A, and falling drops of liquid which is becoming richer in B. In this way it is possible to draw off at the bottom of the column a liquid which after sufficiently intense rectification consists of very slightly impure B, while the vapour escaping at the top consists almost entirely of the substance A.

The way in which the simultaneous evaporation and condensation causes such a progressive separation into the two components can be best understood by a consideration of the phase diagram reproduced in *fig. 4*, in which the temperature is plotted vertically and the composition of the mixture horizontally for a given pressure.

The lower curve indicates the highest temperatures at which the mixtures of various compositions may exist entirely in the liquid phase (liquid curve), while the uppermost curve gives the lowest temperature at which for different compositions the whole can exist in the form of a vapour (vapour curve). A homogeneous mixture of a composition and at a temperature given by a point lying between the two curves cannot exist in a stable condition. If at a given temperature T there is a mixture having a composition lying between the liquid and the vapour curve, it separates into a liquid and a vapour phase, whose stable compositions are indicated by the intersections x_1 and x_2 of the horizontal line corresp-

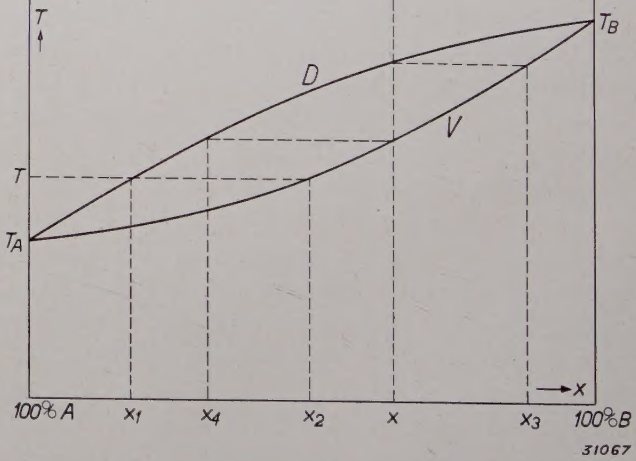


Fig. 4. Phase diagram for the substances A and B with the boiling points T_A and T_B respectively. At a given pressure the temperature T is plotted vertically and the content x (in per cent) of the component B horizontally; in other words, to the left is 100 per cent A and to the right is 100 per cent B. At a given temperature T vapour of a composition x_1 is in equilibrium with liquid of a composition x_2. The first small amounts of liquid which can condense during the cooling of a mixture with the composition x, will have the composition x_3, while the last small amount of vapour which remains upon further cooling will have the composition x_4. D is the vapour curve and V the liquid curve.

onding to the temperature in question with the liquid and vapour curves respectively.

If for example a vapour with a composition x is cooled sufficiently slowly, its composition at first remains unaltered and only its temperature falls, so that therefore its point in the phase diagram of fig. 4 moves downward along a vertical line until the vapour curve is reached. If more heat is then removed from the mixture, it is able to condense a small quantity of liquid of the composition x_3, while the composition of the vapour remains practically x. Upon further cooling the amount of liquid steadily becomes greater while at the same time it becomes richer in component A with the lowest boiling point, because the point in the phase diagram belonging to the liquid phase moves toward the left along the liquid curve until the liquid has the composition x and there is no more vapour. At the same time the vapour phase has also been cooling off and its composition has been changed in the way indicated by the motion of its point in the phase diagram along the vapour curve until the last remaining trace of vapour has reached the composition x_4 and is therefore much richer in component A with the lowest boiling point than the original mixture. The homogeneous liquid with a constant composition x then cools further while its point in the phase diagram moves vertically downward.

In the foregoing discussion we have actually assumed that the processes always occur so slowly that the complete equilibrium between vapour and liquid is never upset. In practice this cannot of course be achieved, and the compositions of the vapour and liquid phases, between which equilibrium has not been completely established, always lie in the shuttle-shaped region in the phase diagram between the vapour and liquid curves. What takes place in a rectification column can therefore be described as a long series of such steplike exchanges between vapour and liquid of different compositions, which, however, always remain within this shuttle-shaped region of the phase diagram. It will immediately be clear from fig. 4 that at temperatures half-way between the boiling points of the two components A and B considerable separation can be obtained, and that this separation takes place over only a few stages at the middle of the column, while in the neighbourhood of the extremities the compositions for successive stages do not vary very much. With a finite number of stages it is of course impossible ever to effect a complete separation, no matter how intimate one makes the contact between liquid and vapour. In order to approach as nearly as possible the ideal case of an infinite number of stages, it was at first thought advisable to fill the column with bodies having a large surface, but it was found that the contact between vapour and liquid became too poor, so that at present the column is divided into a large number of stages as shown diagrammatically in *fig. 5*.

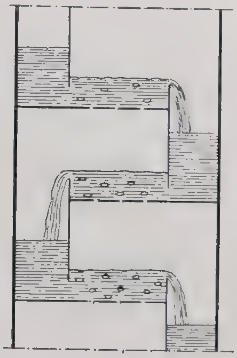


Fig. 5. Diagram of a rectification column built up in stages in which the liquid runs over overflow partitions and falls while the vapour bubbles up through the liquid through small holes in the floor plates. This arrangement is for the promotion of a very intimate contact between liquid and vapour.

When a rectification column is divided into a large number of stages one above the other (fig. 5) provision must be made by the introduction of overflow partitions that the liquid always remains at a definite height above the floor plates of the stages and runs continually over the edge into the stage below. Furthermore for the sake of good contact between liquid and vapour the vapour must be made to bubble up through the liquid through small holes in the floor plates. The number of such stages in ordinary rectification columns is from 10 to 50. The diameter and height of the stages are so chosen that the vapour carries as little liquid as possible in the form of drops, so that the whole construction depends very much upon the nature of the mixture to be separated.

Components of air

In the following *table I* are given the percentages and the boiling points of the different components of air; the 0.5 to 4 per cent of water vapour which is always present in ordinary air is assumed to have been removed from it. The table thus refers to dry air.

In this table the components of air are given approximately in the order of the proportion occurring in ordinary air. The proportion of hydrogen and methane are not accurately known, and seem to be variable, which is also the case with the carbon

Table I

Components of air	Volume per cent of dry air	Boiling point in °C
nitrogen	78	— 196
oxygen	21	— 183
argon	0.9	— 186
carbon dioxide	0.03	— 79
neon	0.0015	— 246
helium	0.0005	— 269
hydrogen	about 0.0005	— 253
krypton	0.0001	— 151
xenon	0.00001	— 109
methane	about 0.0001	— 165

dioxide content. Argon, neon, helium, krypton and xenon are the rare gases. The smallness of the amounts of these gases is illustrated by the fact that upon treatment of 1000 cu. m of air at 1 atmosphere per hour one can obtain not more than 9 cu.m of argon, 15 l. neon, 5 l. helium, 1 l. krypton and 0.1 l. xenon.

It is plain from the above table that air may in the first approximation be considered as a mixture of nitrogen and oxygen. For the separation of air into these two components rectification is the most suitable method. By combining liquefaction according to fig. 2 and rectification according to fig. 3 one arrives at the oldest and simplest method of so-called simple rectification (*fig. 6*).

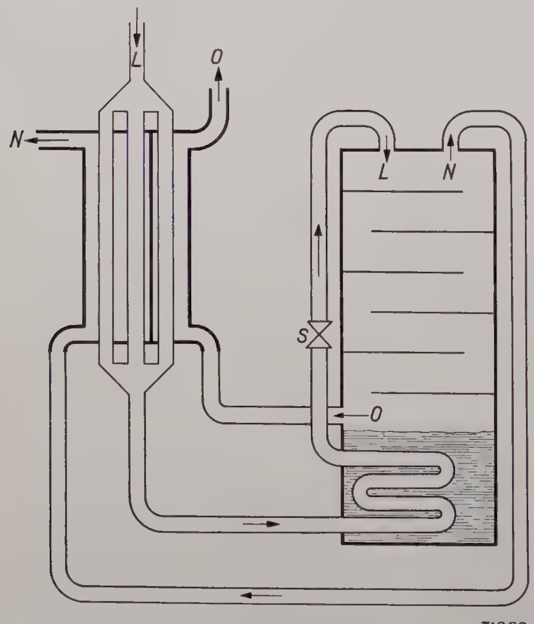


Fig. 6. Diagram of an installation for simple rectification. The air L flows into the top of the interchanger at an ordinary temperature. It is cooled here and then flows into a cooling coil through the liquid container at the bottom of the rectification column where it is liquefied. It then expands through the needle valve S and flows in liquid form into the top of the column. At the bottom of the column oxygen gas is drawn off, and at the top nitrogen with at least 7 per cent of oxygen escapes; both of these gases flow in separate lines upwards through the interchanger at the top of which they are obtained at about normal temperature.

In this process the air at an ordinary temperature enters the top of the interchanger where it is cooled by the oxygen and nitrogen flowing in the opposite direction which have been separated from each other in the rectification column. The air, which although cooled is still in the gaseous form, leaves the interchanger at the bottom, flows through a cooling coil in the reservoir containing liquid oxygen below the rectification column so that it is still further cooled and liquefied. It then expands through the needle valve S and in the form of liquid air flows into the top of the rectification column. This does not correspond exactly to the principle of rectification are discussed in connection with fig. 3, because in that case the mixture was introduced into the column at a suitable height, while liquid nitrogen was introduced at the top. For this reason with simple rectification only very impure nitrogen gas escapes at the top of the column.

The liquid air then flows down through the column becoming poorer and poorer in nitrogen. In the container below the column practically pure liquid oxygen is collected. This is again entirely evaporated by the heat which is removed from the air flowing through the coil, and most of it ascends into the column again, while the rest is drawn off and sent up through the interchanger, at the top of which oxygen gas is finally obtained at about a normal temperature.

Because of the high degree of impurity of the nitrogen produced, we cannot obtain more than 71 per cent of the oxygen from the air in a pure form by this method. The gas which escapes at the top of the column is of course much richer in nitrogen, but must still always contain at least 7 per cent of oxygen since it is in equilibrium with liquid air containing 21 per cent of oxygen.

In order to obtain a higher yield of oxygen and nitrogen in a purer form, double rectification (*fig. 7*) is applied. Between the interchanger and the rectification column which works simply at slightly more than atmospheric pressure, a second rectification column is introduced which works at a pressure of about 5 atmospheres. The liquid air flowing out of the needle valve S is now admitted to this pressure column at a suitable height. The nitrogen vapour at about 5 atmospheres which escapes at the top of the pressure column is conducted into the condenser C which is situated in the container filled with liquid air below the ordinary column. The temperature of the oxygen boiling at atmospheric pressure is just low enough to condense the nitrogen vapour at a pressure of 5 atmospheres. Part of this practically pure liquid nitrogen drips down into the pressure column and is further admitted through a needle valve S_2 into the top of the ordinary rectification column where it again drips down. Since at 5 atmospheres the limiting curves in the phase diagram of fig. 4 lie much closer together than at 1 atmosphere, the separation in the pressure column is not very complete. The liquid container below the pressure column contains oxygen which is still quite rich in nitrogen. This liquid is admitted into the ordinary rectification column through a needle valve S_1 at a suitable height, and the further separation into oxygen and nitrogen takes place there. This rectification is complete within only a few per cent. Such an installation for rectification, in use in the Philips rare gas plant, is shown in *fig. 8.*

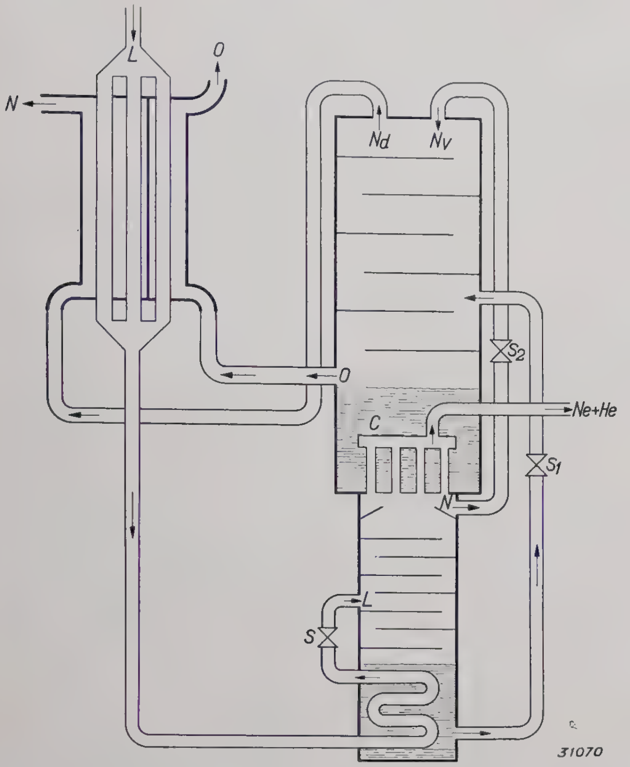


Fig. 7. Diagram of double rectification. Between the interchanger and the ordinary rectification column of fig. 6 another rectification column has been introduced which works at a pressure of about 5 atmospheres. L air; N nitrogen, pure to within several per cent, O pure oxygen; S, S_1, S_2 needle valves and C condenser.

It would perhaps be possible to introduce a rectification column for 20 atmospheres in front of that for 5 atmospheres. This, however, does not offer much advantage since the phase diagram at that pressure is so much narrower than at 5 atmospheres. It is therefore of little use to try to carry the separation of a mixture further by this method.

The interchanger is a very important part of the whole installation, because it is necessary for efficient operation that the temperature difference between the air entering and the separation products obtained should be only a few degrees. This is achieved by allowing the compressed air to flow through a bunch of narrow tubes whose inner diameter is only about 5 mm and which are often made in the form of spirals of 20 or 30 metres. The outside of these tubes is bathed by the products of the separation while the currents inside and outside the tubes are more or less perpendicular, so that the occurrence of an active eddy current provides for more complete transfer of heat. All the parts of such an installation which reach low temperatures should be made of copper or brass, since these materials keep their favourable mechanical properties even at low temperatures, while most other substances quickly become brittle. Since "tin disease" does not occur at these low temperatures all soldered joints in these apparatus can be made with tin.

In the separation of air water vapour and carbon dioxide are very disturbing, since they become solid at the low temperature and may therefore stop up the connections. The air must therefore be carefully freed from these substances in advance. For drying (see *fig. 9*) use is made of solid potassium hydroxide. Upon taking up water this substance forms a saturated solution of potassium hydroxide which can be drawn off from the drying apparatus. This solution is then used in the washing towers where the air to be used is freed of carbon dioxide. In this way potash is formed which can be used again in the manufacture of glass in the smelting mixture. In this way the various parts of a great industry are bound closely together.

Rare gases

The most plentiful rare gas occurring in air is argon which has a boiling point lying between those of oxygen and nitrogen, so that this gas has the tendency to collect at the middle of the rectification column. The argon can be separated by drawing off the oxygen vapour which is rich in argon from the main column and then rectifying later separately in an auxiliary column. The argon is thereby freed from the main mass of the oxygen, and this is usually sufficient for practical purposes, since the last traces of oxygen can easily be removed chemically. This is, however, more difficult with nitrogen, and therefore too high a content of nitrogen is simply avoided by drawing off the mixture for the auxiliary column somewhat nearer the oxygen end of the main column, so that almost no nitrogen is taken with it.

For a given use nitrogen with a very small content of argon was required. In order to find out how much argon the normally prepared nitrogen contained, a method of analysis has been worked out in our laboratory ¹). This method is based upon the very rapid absorption of nitrogen by metallic lithium prepared in a suitable way, which phenomenon was discovered in the previous century ²). In these measurements it was found that normally prepared nitrogen contains only very little argon.

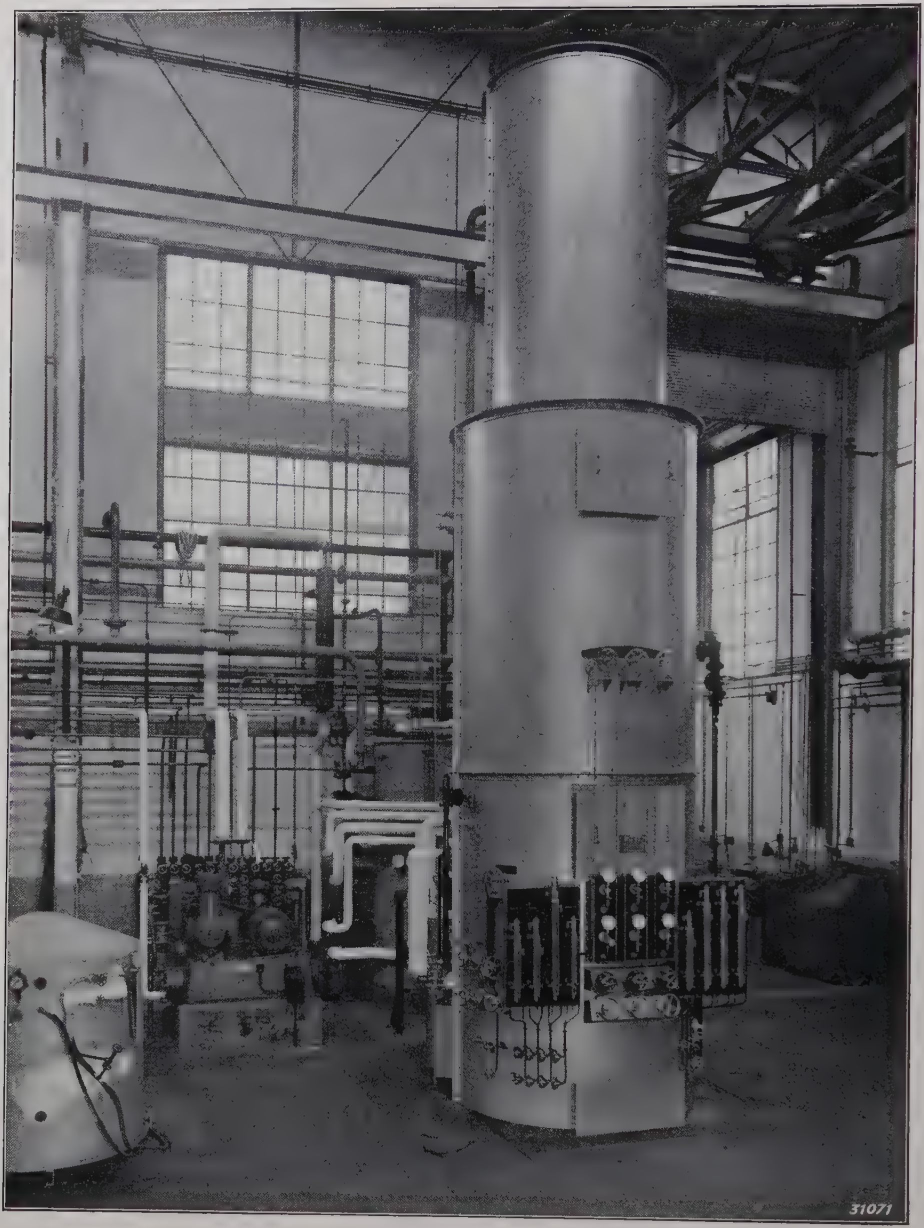


Fig. 8. A modern installation for the separation of air by the Linde method. In the large column, inside a thick layer of insulation material are four rectification columns and the necessary interchangers. On the outside may be seen various regulating taps, indicators of the liquid levels, manometers, etc. At the extreme left there is a supply tank for liquid oxygen. In the background may be seen an ammonia cooling system with which the air at a pressure of about 100 atmospheres is cooled to −20° C, which serves to dry it, and at the same time to promote a more economical working of the separation apparatus.

Neon and helium, as may be seen from the table, have boiling points which lie far below those

---

¹) J. A. M. van Liempt, Rev. trav. chim. Pays Bas **56**, 310, 1937.

²) Guntz, C. R. Acad. Sci. Paris **120**, 777, 1895.

of the other components of air. They need not therefore be separated by a special rectification, but simply escape as a volatile fraction out of the top of condenser *C* in which most of the nitrogen becomes liquid. The neon and helium drawn off at that point then still contain some nitrogen and hydrogen as impurities which can easily be removed. Finally it is also possible to separate neon and helium from each other by absorption and desorption on active charcoal, without it being necessary to use temperatures lower than those of nitrogen boiling in a vacuum (—220° C).

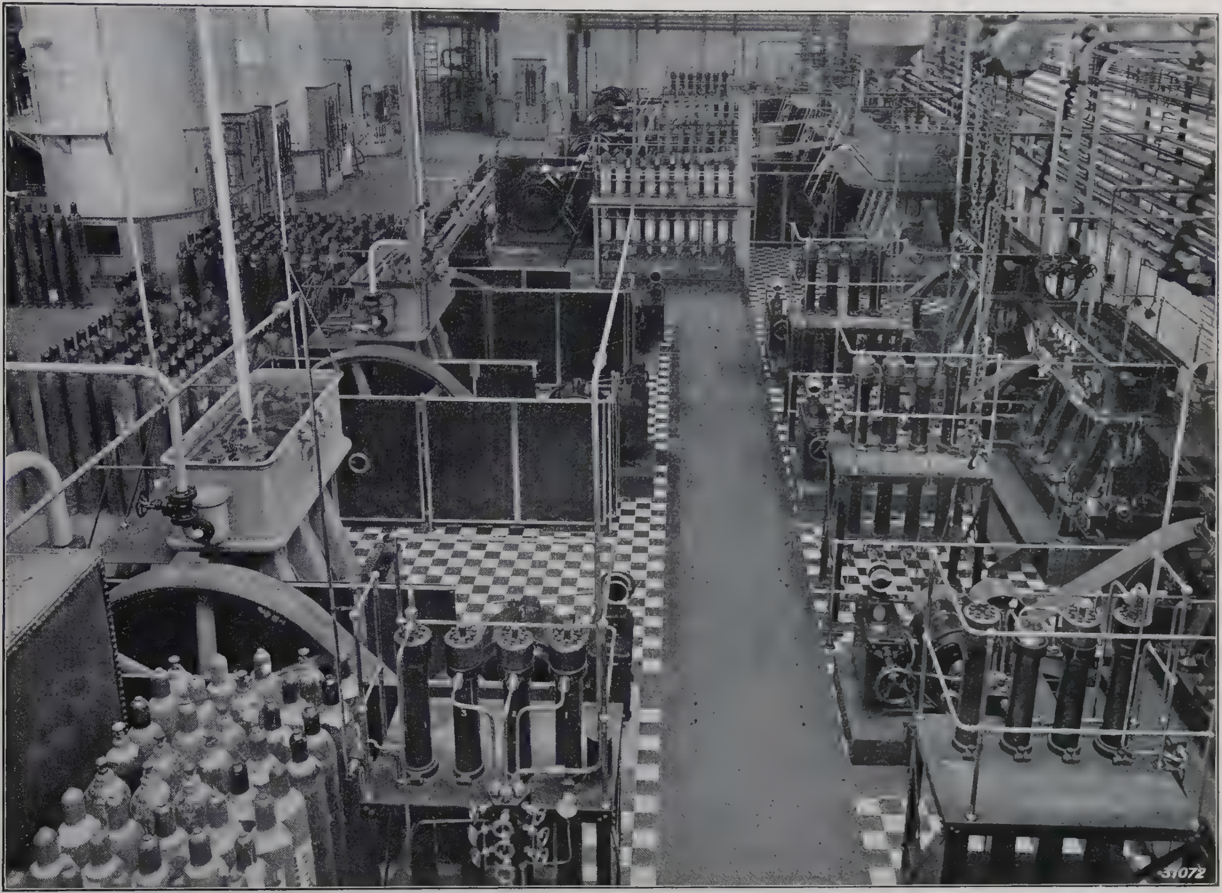


Fig. 9. View of part of the rare gas plant. In the foreground to the left and right are several smaller compressors for oxygen, nitrogen, etc. In the background to the right may be seen four large air compressors. In the centre background stand racks of steel cylinders filled with solid potassium hydroxide for drying the strongly compressed gases. To the left in the background may be seen several installations for the separation of air.

Since they have relatively high boiling points krypton and xenon collect mainly in the liquid container below the main column, which contains oxygen for the most part. The krypton and xenon can only be separated from the oxygen by a special rectification. Because of the very small quantity of these rare gases this is a very elaborate process in which, however, there are no fundamentally new methods used. There is, however, one very great difficulty in this process, namely the fact that the methane which occurs in variable amounts in the air has about the same boiling point as krypton, so that it is collected with the krypton in the liquid oxygen. This may have serious consequences since liquid oxygen together with a combustible substance like methane can easily form an explosive mixture. In order to avoid accidents therefore the strictest precautions must be taken in the preparation of krypton and xenon.

THE EQUIPMENT OF BROADCASTING STUDIOS

621.396.712.3

A description is given of the radio technical equipment of a broadcasting station. The installations of the A.V.R.O. studio and more briefly that of the K.R.O., studio both at Hilversum (Netherlands) are discussed as examples. Special attention is paid to the construction of the central control tables and the provisions for organizing the broadcasts.

There are two main factors to be considered in the equipment of a broadcasting studio. In the first place the sound which is to be broadcast must be conducted to the transmitter in the required purity and freedom from interference, the correct intensity and the desired relative intensities. In the second place opportunity must be given for the preparation and the smooth carrying out of the very varied daily programms. It is especially the first factor which is of influence on the elements of broadcasting. The second factor chiefly determines the size of the installation and makes necessary the introduction of a series of appliances concerned with organization.

In the following we shall give a description of the equipment and running of a broadcasting station, taking as example the A.V.R.O. studio in Hilversum. The above-mentioned factors will serve as a guide [1]).

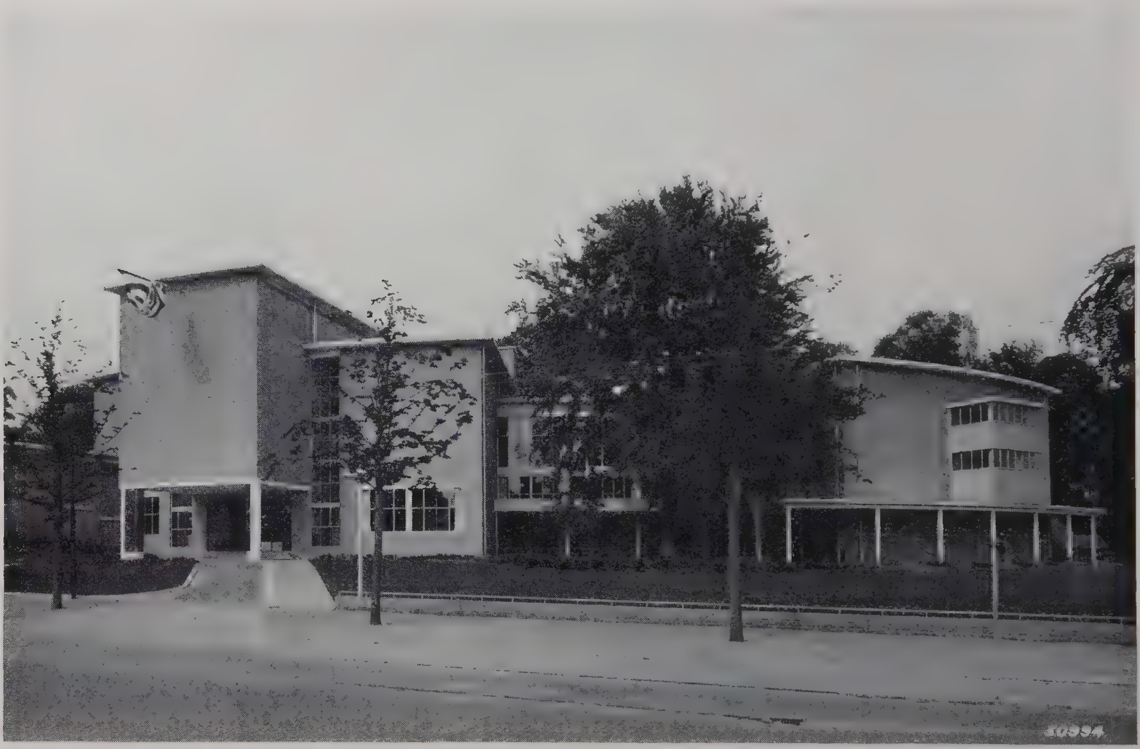


Fig. 1. The A.V.R.O. broadcasting station (1936) in Hilversum (Netherlands). The large windowless wall spaces serve to cut off the studios as much as possible from the outside world.

Composition of the broadcast programme

In order to obtain an insight into the needs of a broadcasting station we shall first consider the components which make up the daily programme. In the first place there are the musical items of all kinds, orchestra music, chamber music, jazz, and solo performances. Then there are lectures, and plays in which not only the voices of the different players but also a great variety of sound effects play a part. The sound effects are intended to give the acoustic atmosphere and are heard between the dialogues or as a background; a special form of acoustic illusion is the suggestion of great emply space by means of a long reverberation. In addition gramophone music forms an important part of the programme. In addition to all this are the communications of the announcer. Furthermore there is an intermission signal and a time signal, and

---

[1]) The design of this studio installation was made according to the recommendations of Prof. Dr. Ir. W. Th. Bähler and Ir. F. R. Th. Kröner; it was executed by N.S.F.-Philips.

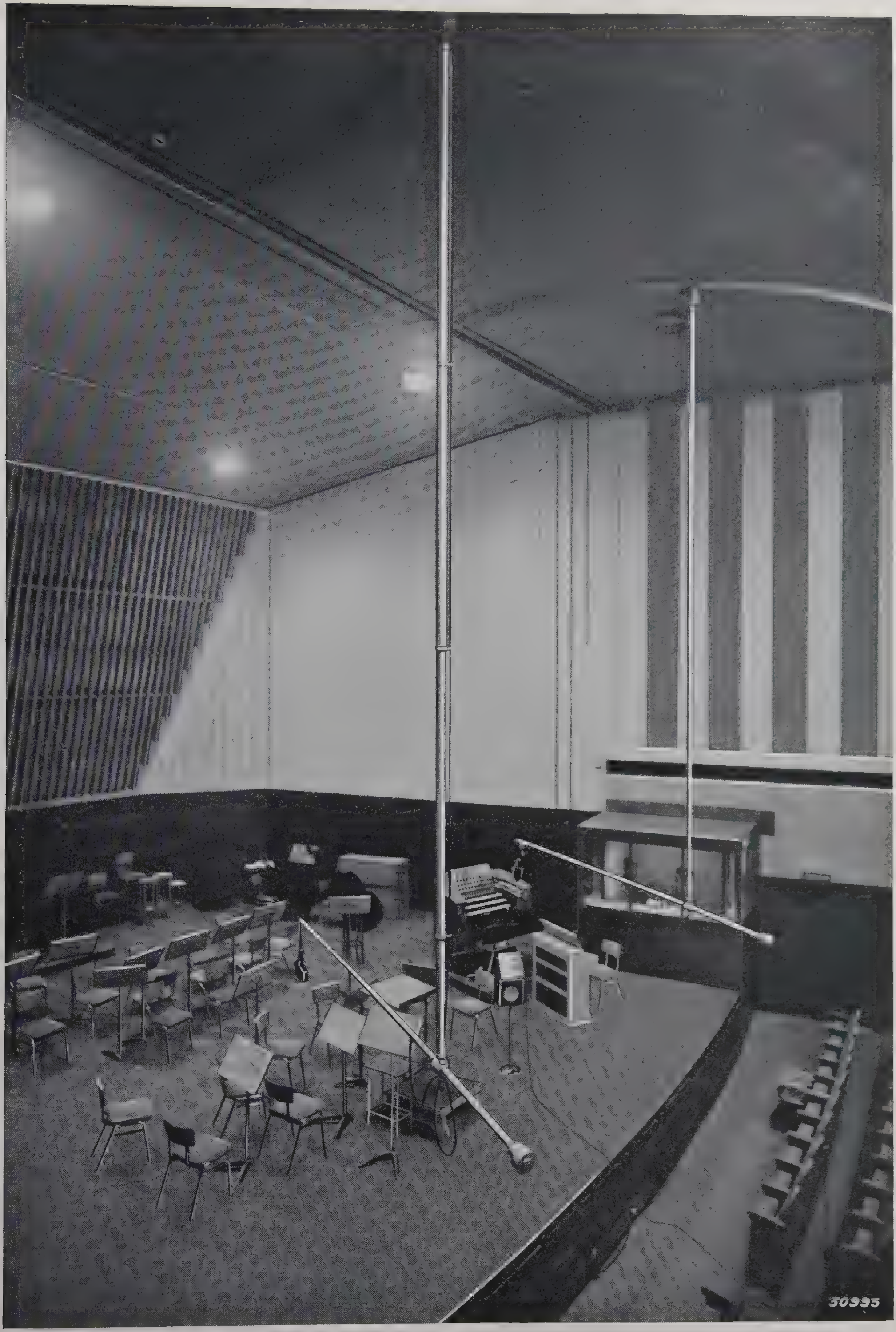


Fig. 2. Platform of the large concert hall in the A.V.R.O. building. Two suspended microphones hang from rails in the ceiling along which they can be moved in order to be able to place the microphones as nearly as possible at any desired spot. In the background may be seen the mixing cabin which is separated from the hall by triple glass windows.

finally it is sometimes also necessary, for instance in the case of running commentaries, that a broadcast, transmitted by telephone line to the broadcasting studio, be there prepared for the radio transmitter with or without the addition of sound produced in the station itself.

Each of the different kinds of broadcast here mentioned requires a suitable studio for its production. The A.V.R.O. studio (*fig. 1*) contains among other rooms, a large and a small concert hall, a dance music studio, a large and a small theatre studio, rooms for speakers, for the announcer, for producing sound effects, etc. The sound produced in the studio can be provided with any desired reverberation by means of the so-called echo cellar. The latter is a room with a very long reverberation in which a loud speaker and a microphone are set up. When the loud speaker reproduces the sound coming from the studio, the microphone takes up the reverberation in the echo cellar and this can be added electrically in the required amount to the sound to be broadcast.

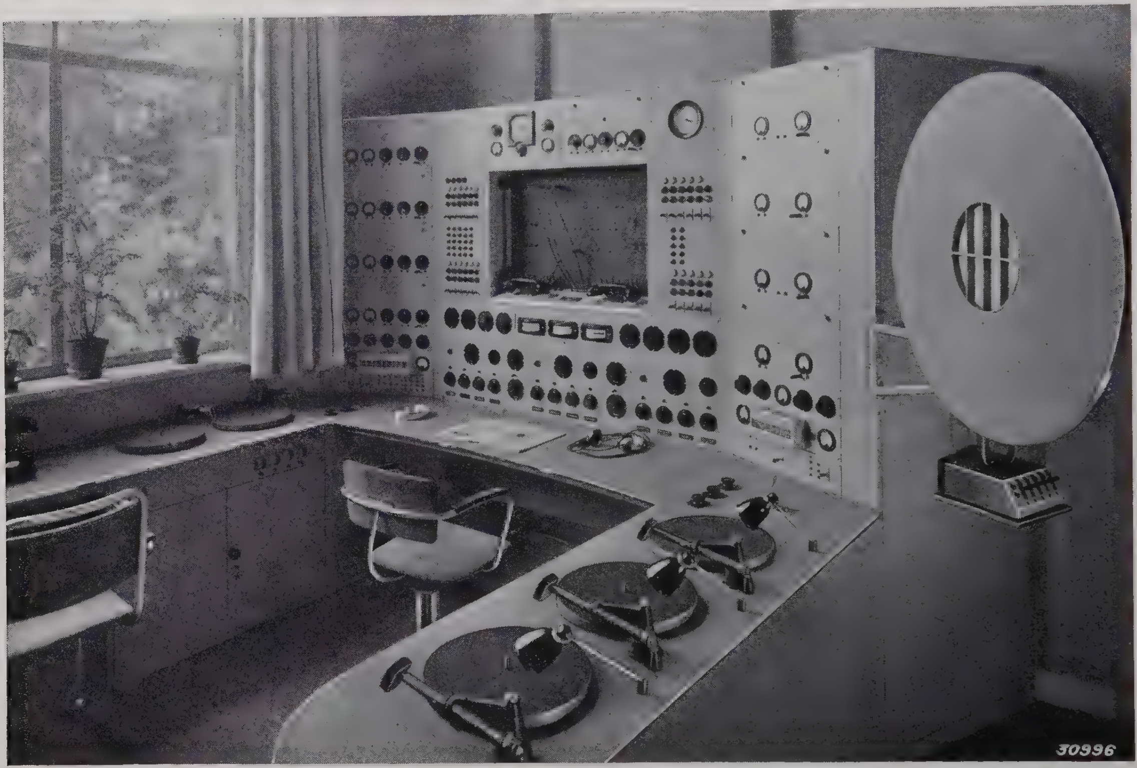


Fig. 3. A central control table of the A.V.R.O. Just above the top of the table, immediately in front of the sound mixer's place may be seen the control knobs of the three fading units; above them the three measuring instruments for the maximum, minimum and average levels; in the centre of the panel the central switchboard on which the conductor of the transmission can connect the available faders of the fading units to all the incoming connections from microphones, gramophones and telephone lines, to the signal lamps, and push buttons for light signals in the studios. To the left and right of the control panel are the racks with the amplifiers. To the extreme right the monitor loud speaker. An either side of the mixer a group of turntables for gramophone records is placed.

Amplification, mixing and regulation of the sound

We shall now follow the course of the sound in more detail from the studio to the transmitter.

Each studio, according to its size, contains several microphones which can be connected at various spots in the room. In the large concert hall of the A.V.R.O. studios (*fig. 2*) there are for example 5 microphones, while there are 10 microphone plug boxes. The microphone currents are amplified in microphone amplifiers which are set up in the neighbourhood of the plug boxes in order to make the microphone currents somewhat less sensitive to disturbing influences directly before their further journey.

The amplified microphone currents are now "mixed", *i.e.* that the currents coming from different microphones and different lines are added together by a person who in general directs the whole broadcast, and are given the required relative intensities by means of adjustable resistances (faders). The resulting current, after being amplified again, is then regulated in order to bring it to the correct transmission line level. This level must be so chosen that on the one hand the loudest passages of the sound experience no disturbing non-linear distortion, while on the other hand the softest passages are still sufficiently far above the noise level. Considering the great variations in intensity which occur in speech and music, continual control and regulation of the material broadcast is necessary. A control table (in the A.V.R.O. studio), where the mixing and regulation takes place, is shown in *fig. 3*. To the extreme right may be seen the monitor loud speaker, which makes it possible for the person directing the broadcast to hear it. In the regulation, however, the sound mixer does not allow himself to be led exclusively by the qualitative sound impression from the loud speaker, but by the quantitative indications of three measuring instruments (for the loudest and the softest passages in the sound and for the average sound intensity respectively), which may be seen in fig. 3 in the centre of the control panel, directly in front of the place of the mixer.

In the case of certain broadcasts, such as for example a concert with soloists, it is desirable that the mixing of the contributions by the different microphones be carried out by someone who is in visual contact with the performers. The largest studios in the A.V.R.O. station are therefore provided with small cabins in which the currents from all the microphones, after amplification, come together on a mixing table. The cabins are made soundproof by triple glass windows and the mixer receives the sound through headphones or a loud speaker which corresponds in function to the monitor loud speaker beside the central control table in fig. 3. In fig. 2 the glass mixing cabin may be seen in the background. *Fig. 4* shows a mixing desk such as is used in these cabins. The microphone currents mixed in the cabin are again conducted to the central control table.

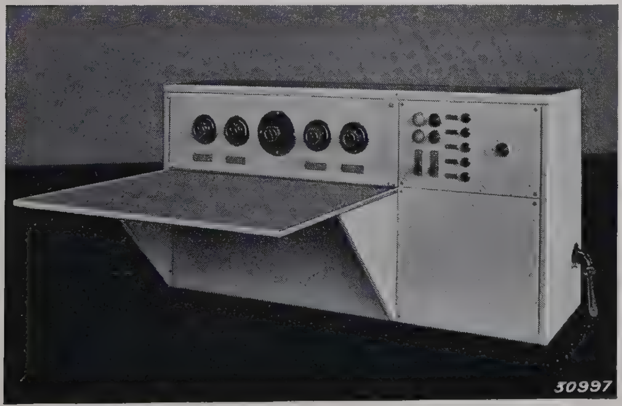


Fig. 4. Small mixing desk which is used in the mixing cabins of the A.V.R.O. studios.

Installation of the central control table

In broadcasts to which many microphones set up in different rooms contribute, it would be too complicated if all the currents had to be regulated separately every time it was necessary to regulate the currents of a few of the microphones. In a play for example in which a sound effect occurs which is made up of different sounds, the sound effect is wanted as a whole or not at all. Therefore the regulators (faders) are arranged on the mixing table in groups of four, which can be regulated again as a single unit. The control table in fig. 3 contains three such fading units.

After mixing, the sound of each fading unit is amplified in its own amplifier *A* (*fig. 5*). Each *A* amplifier contains three end stages *a*, *b*, *c* in parallel, whose volume can be regulated separately. As may be seen in the diagram of fig. 5 the outputs *a* of all three *A* amplifiers are again joined, just as the three outputs *b* and *c*. The currents of the combined outputs *a* are intended for transmission. The combined outputs *b via* a common regulator serve for feeding the so-called sound effect loud speakers in the studios. In this way a sound effect can be introduced acoustically into the programme. In the performance of plays this is very desirable, in order that not only the listeners but also the performing artists themselves may feel the atmosphere which is being suggested by the background noise. In such an acoustic mixing of sound effects care must of course be taken that no acoustic feeding-back occurs. The control knobs *a* and *b* of each unit are therefore locked in such a way that *b* cannot be switched on when *a* is working; no current can be fed to the sound effect loud speakers from a microphone which is already feeding the transmitter, *i.e.* it cannot be fed to the sound effect loud speaker in the same room with the microphone. On the other hand, however, when knob *b* has been used and it is therefore known that no acoustic feeding-back occurs, the knob *a* of the same unit (sound effect unit) can be put in operation: the sound effect is then added directly by electrical means to the sound sent to the transmitter. By the division into three fading units two sound effects can be prepared simultaneously in addition to the main programme, and it is possible to pass immediately from one to the other.

The remaining outputs *c* serve, again *via* a common regulator and an amplifier, to feed the loud speaker in the already mentioned echo cellar, where the desired reverberation can be obtained. Because of the fact that the three outputs of each *A* amplifier can be regulated separately, it is possible to provide each of the three contributions to the whole sound from the three fading units separately with the desired reverberation. The current of the echo microphone (after amplification and regulation) is added to the currents of the *a* outputs.

The complete programme so obtained is conducted to two amplifiers (*B* and *C*) in cascade arrangement. To these amplifiers also is sent the already pre-amplified microphone current from the announcer in his cabin. The sound of the whole programme can here again be regulated with respect to the sound from the announcer with a single manipulation by a main regulator. The output of amplifier *C* is again divided into three and supplies as desired the telephone line to the transmitter, the monitor loud speakers in the studio (beside the control table, fig. 3, for example) *via* a power amplifier, and an apparatus for sound recording.

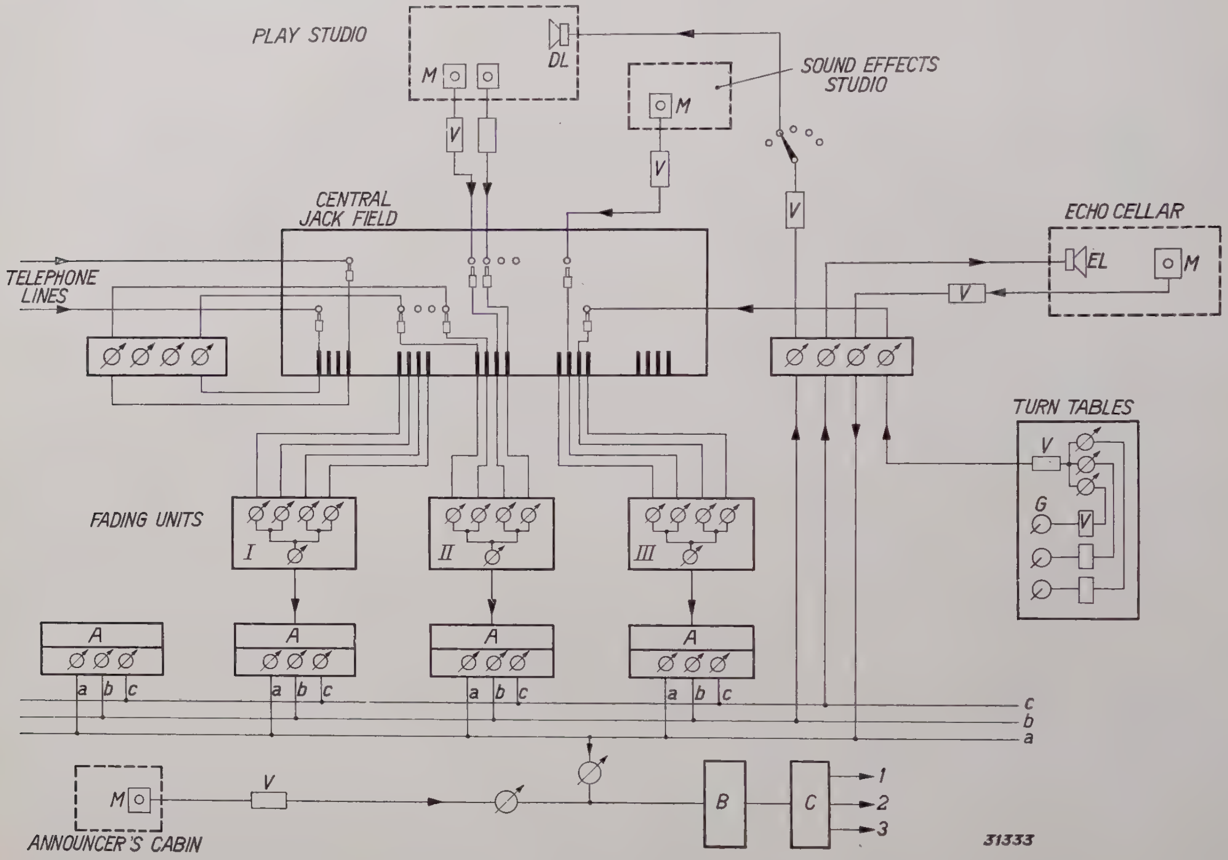


Fig. 5. Simplified diagram of the central control table. On the central switchboard several connections of the three fading units *I*, *II* and *III* are indicated, which may for instance occur during the performance of a play. The "programme unit" (*II*), in the case imagined, receives the currents from two microphones in the play studio and from two telephone lines (which have first been put through the line regulators). The "sound effect group" (*III*) which is in use receives currents from the sound effect studio and from the turn-tables. Each fading unit has an amplifier *A* with three outputs *a*, *b* and *c*, which are combined as shown. The *b* outputs feed the sound effect loud speakers (*DL*) in the studios, the *c* outputs the loud speaker (*EL*) in the echo cellar. The currents from the echo microphone and from the microphone in the announcer's cabin are added to the currents of the output *a*, and together amplified in amplifiers *B* and *C*. The three outputs *1*, *2* and *3* of *C* serve to feed the transmitter, the monitor loud speakers and an apparatus for sound recording. *V* are various amplifiers, *M* microphones, *G* gramophone pick-ups.

Amplifiers *A* and amplifiers *B* and *C*, with the necessary reserves, are set up to the left and right of the control panel in fig. 3. On either side of the place of the sound mixer may also be seen a number of turn-tables for gramophone records. With each turn-table is a so-called bas corrector, a gramophone amplifier and a volume regulator. The sound from all five gramophones is sent together to another amplifier with a filter for removing the noise of the needle, and *via* a main regulator to one of the fading units.

The connection of the different programme contributions to the fading units takes place by means of a central switchboard which may be seen in the middle of the control panel in fig. 3. The connections of all the microphones coming from the studios, of all the groups of microphones coming from the small mixing cabins, of the group of gramophone pick-ups and a number of telephone connections for music and speech coming from the outside end in sockets on this switchboard. Each fader of the fading units can by means of a cord and jack be connected to any desired socket. The sound mixer can then place a sign beside the regulator on which is indicated the socket connected. The signs are held in place magnetically so that it is very easy to change them.

Organization of the broadcasts

The A.V.R.O. broadcasting studio contains two entirely similar and independent central control tables like the one described above. This makes it possible to supply two transmitters at the same time with different programmes, or to rehearse a programme while another is in progress (the small fading units can also serve this purpose), or to record a programme for later transmission.

The centralization of the direction of a broadcast on a central control table permits satisfactory oversight of the whole process, and makes possible a large number of combinations of connections. This centralization, and especially the simultaneous operation of two such centres, requires special provisions for the rapid preparation of all necessary connections, for the avoidance of errors and for the necessary contact of the director of the broadcast with the performers and the technicians. We shall briefly discuss these provisions in the case of the A.V.R.O. broadcasting studio.

One studio cannot of course be served by both of the control tables at the same time. There is therefore a switch for each studio which connects all the microphone and other lines simultaneously with one or the other of control tables. The switch is driven by a motor. By means of a locking device care is taken that the motor can be switched on at one table only when the studio in question is not connected with the other control table. By the joining of all the connections from a studio in one switch the switching over from one table to the other takes place very quickly, and it is impossible for necessary connections to be forgotten. In the whole building microphone and other connections are carefully separated. This separation also is carried through in the switches by constructing the switch in two parts which are electrically shielded from each other. A similar switch provides that the telephone line to the transmitter can only be connected to the output of one of the control tables. With the same switch control loud speakers placed at different points in the building are connected to that control table. In *fig. 6* may be seen a cabinet with a group of these switches. The switches as well as all the rest of the common auxiliary apparatus of the two control tables are set up in an instrument room shown in *fig. 7*. On the line terminating bay in the centre of the panel shown here the music and speech lines

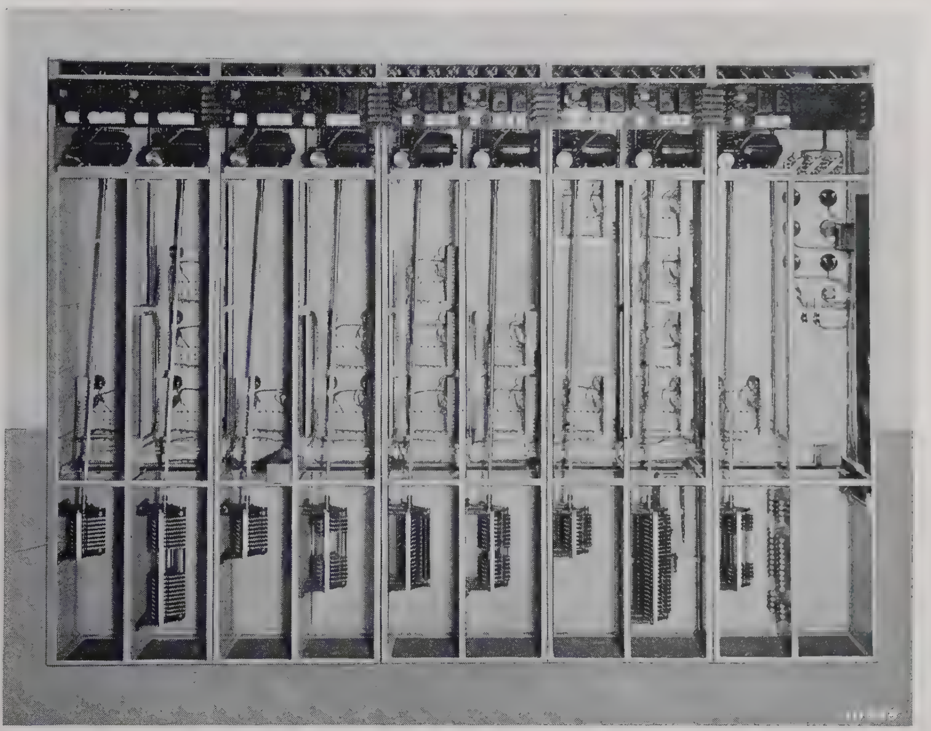


Fig. 6. Cabinet with switches, seen from the back. In order to avoid disturbances the motors (top) are kept, by means of long driving shafts, at a suitable distance from the microphone connections which lead to the switching devices mounted below.

coming from outside the building are connected to the switchboard of one or the other control table by operators.

A locking device is also necessary for the echo cellar: when it is connected to one control table, the echo loud speaker must not of course reproduce any sound from the other control table, since otherwise the two programmes would be mixed together in the echo microphone.

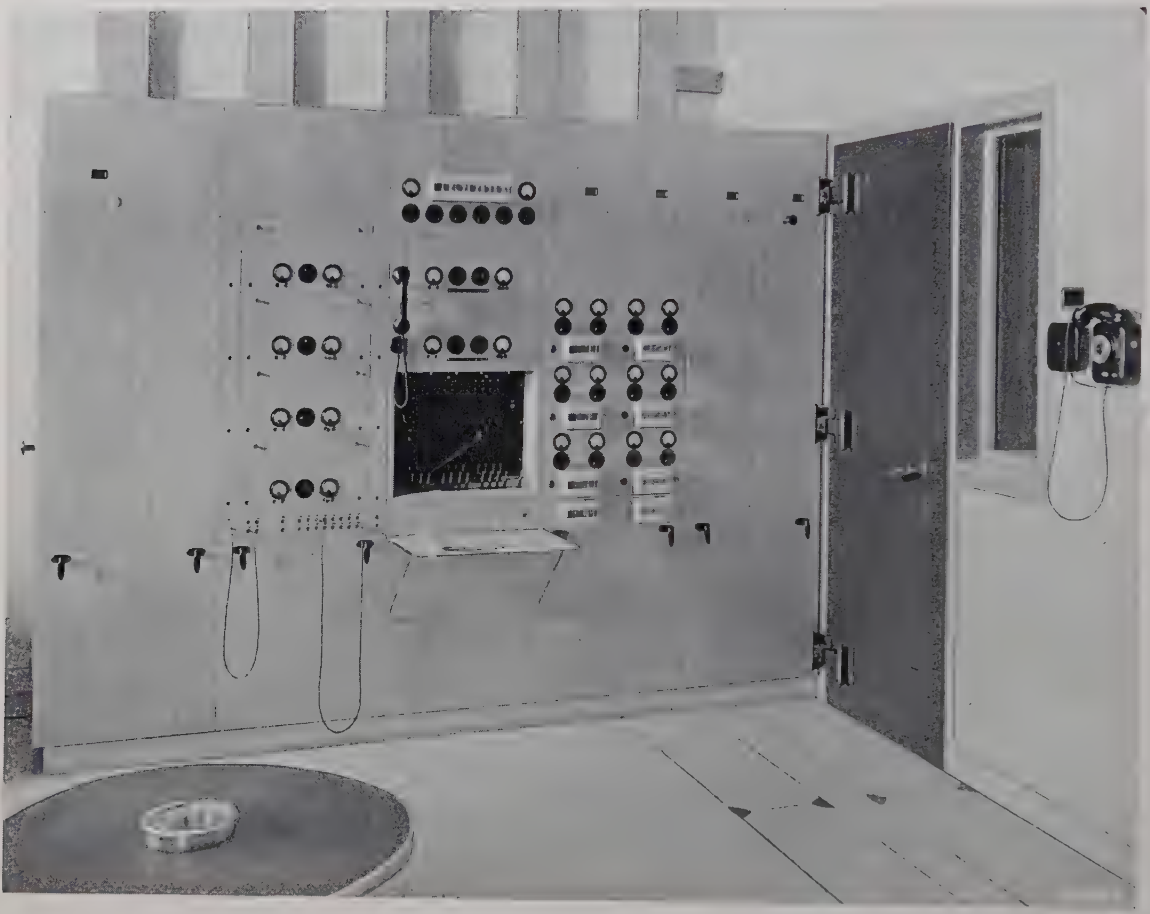


Fig. 7. Switch panel with amplifiers and line terminating bay in the instrument room of the A.V.R.O. building. This panel also contains two correction amplifiers by which the low and/or high frequencies of the sound which comes in along telephone lines can be amplified to 20 dB with respect to the average frequencies. The levels of the telephonic contributions to the program are made equal to that of the other parts of the programme by a set of line regulators on the control table (fig. 3, to the left next to the three measuring instruments under the central switchboard): all the sockets on the central switchboard then carry a level of –23 dB with respect to the transmission line level (5 mW).

The contact between the director, the performers and the technicians is guaranteed by an extensive signalling arrangement. As long as the broadcast has not yet begun the director can give spoken orders to the collaborators by means of a "talk-back" microphone on the control table which can be connected with the "talk-back" loud speaker in every studio. As soon, however, as the broadcast begins no more orders must be heard in the studio. The "talk-back" microphone is therefore automatically disconnected when the control table is connected to the line to the transmitter. When the broadcast is about to begin, this fact is announced in the studio by a green light signal. From the studio a white light signal is then given to the control table as a sign that the performers are ready. A red signal in the studio then gives the signal "Begin". Five other commonly occurring instructions or warnings such as "speak louder", "five more minutes time", etc. can be given by means of transparant signs which the director can switch on with a series of push buttons on the control table (next to the central switchboard in fig. 3).

If the small mixing cabin of a studio is in use, the signalling is done *via* this. Furthermore there are control lamps indicating, automatically on each control table which studios are connected to the one and which to the other control table, lamps which indicate that the microphone ampli-

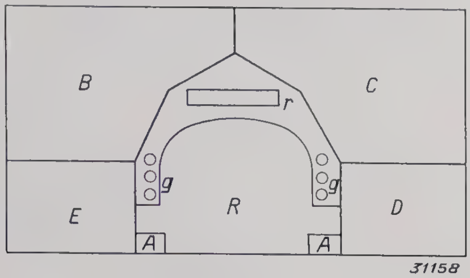


Fig. 8. Plan of the arrangement of the "dramatic control desk" in the K.R.O. building. *R*, dramatic control room with control panels *r*, amplifiers *A* and gramophone turn-tables *g*. The room is in open communication with the studio *E* where the sound effects for the plays are produced and with the small theatre studio *D*. The control room is separated from the chamber music studio *B* and the large theatre studio *C* by sound-proof triple glass partitions.

fiers in the instrument room are connected and others indicating which mixing cabins are being used for a rehearsal, red lamps which light up beside every regulator in the different mixing units as soon as it must be operated, namely when it is connected to a socket on the switchboard and the red signal has been given in the studio. There is of course a telephone connection between all the control tables, the announcer and the larger studios. When one of the telephones on the control tables is taken up the volume of the monitor loud speaker is automatically diminished, so that the telephone conversation is not disturbed thereby.

A control table for broadcasting plays

The equipment of the control tables in a broadcasting studio depends mainly upon the items which receive most emphasis in the composition of the programme. The equipment here described of the A.V.R.O. studios provides for all necessary and desired combinations without any one type of broadcast receiving special emphasis. It would perhaps be interesting to consider an example of a different kind as a contrast. In the K.R.O. broadcasting studio in Hilversum, the radio technical equipment of which was also carried out by Philips, emphasis has been laid on greater visual

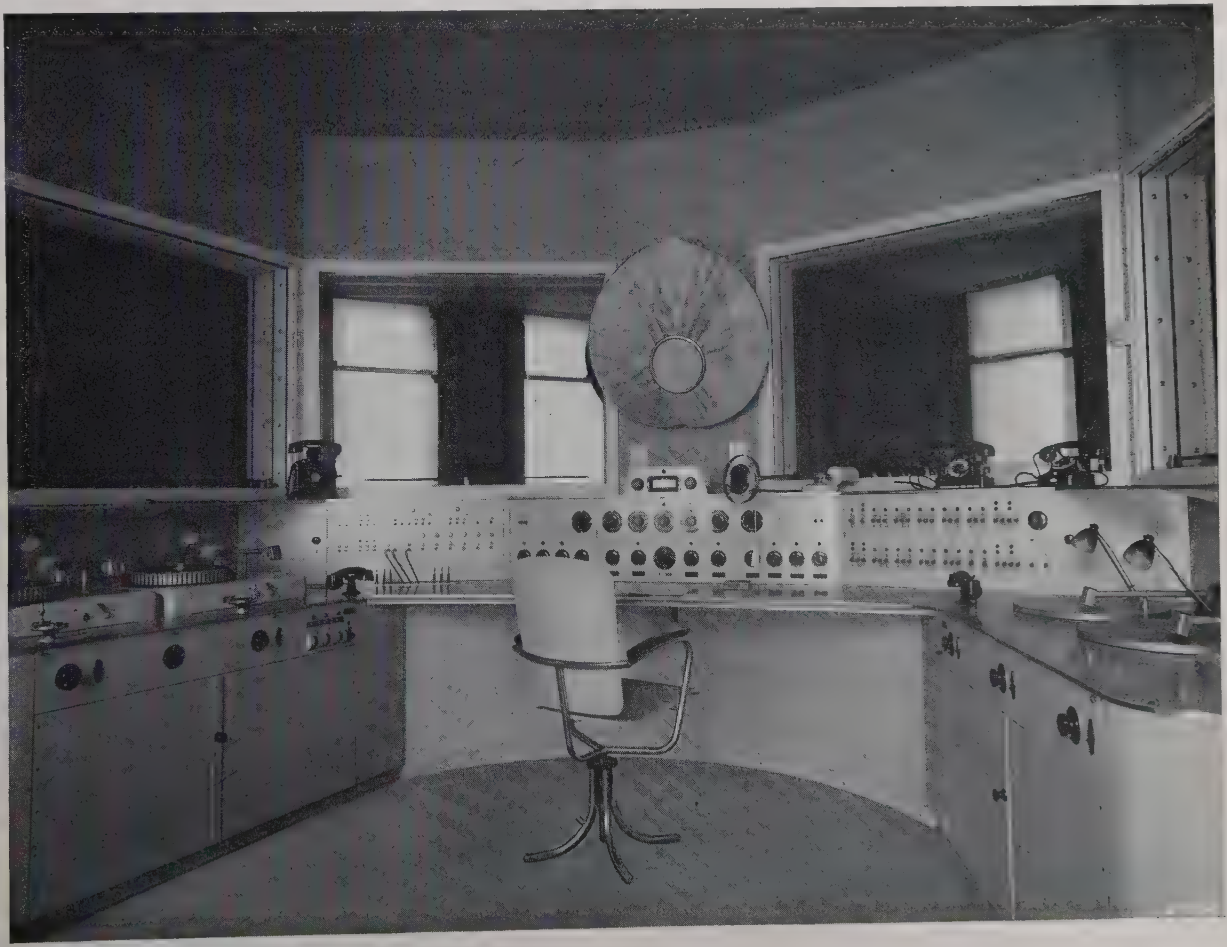


Fig. 9. Dramatic control desk of the K.R.O. Above the control panels is the monitor loud speaker, to the right below it the "talkback" microphone. The amplifiers *A* for this table are in the same, the other amplifiers for the "dramatic control desk" and for the two ordinary control tables are housed in a common instrument room.

contact in the broadcasting of radio plays. In this type of broadcasting it often occurs that various studios work together. A special "dramatic control desk" has therefore been installed which is in visual contact through triple glass partitions with two studios at the same time, namely the large theatre studio and the chamber music studio, while at the same time this control room is in direct connection with the small theatre studio and with the room where the sound effects for plays are produced. *Fig. 8* shows the plan of this arrangement, while *fig. 9* shows the control desk. The dramatic control desk, in contrast to the above-mentioned mixing cabins, is provided with all the necessities for arranging a complete broadcast; it may therefore, like the two ordinary control tables which are also present in the building, be connected directly with the line to the transmitter. The two ordinary control tables for which the need of switching combinations is now less, due to the fact that the dramatic control desk has taken over part of their functions, are more simply equipped than those shown in fig. 3; they each contain only one fading unit for example. In addition to the facilitation of the performance of plays, there is another advantage in the division chosen in the case of the K.R.O. studios: if necessary three transmitters can be furnished with programme at the same time. In order not to decrease too much the number of rehearsals which can take place at once by the combining of several mixing cabins to a single control room, the two ordinary control tables are so arranged that they can be used for a simple rehearsal during a broadcast. The large concert hall again has its own mixing cabin; moreover, one of the control tables is in visual contact with the small concert hall.

Compiled by S. GRADSTEIN.

SOUND DIFFUSERS IN LOUD SPEAKERS

by J. de BOER.

534.861 : 621.395.623.7

Loud speakers have the tendency to exhibit a certain directional effect which becomes more pronounced with increasing frequency. Where such a beam formation of the high tones is undesired, *i.e.*, in small rooms, the directional effect can be neutralized by means of sound diffusers. These are bodies of definite shape and dimensions which are placed in the path of the sound waves. The required diameter of a sphere to be used as a sound diffuser can be derived theoretically. In the loud speakers of the Philips radio sets a cone and vertical partitions in front of the cone of the loud speaker are used as sound diffuser. The most suitable form and dimensions of these sound diffusers for scattering sound are determined experimentally.

When sound amplification is used in halls which have too long a reverberation time, an improvement of the acoustics of the hall can often be obtained by making use of loud speakers with a directional effect ¹). If these loud speakers are directed toward the part of the hall occupied by the audience, the sound intensity is there increased without an amplification of the reverberation necessarily also occurring.

Aside from such special cases, however, a directional effect is generally not desired with loud speakers. This is particularly true in the case of the loud speaker in the home. In this case the listener does not wish the fact of his listening or not listening to the radio to determine the place where he shall sit, but he wishes to be able to hear the programme equally well from any spot in the room. Every loud speaker has a certain natural directional effect. In the following we shall discuss the extent to which this effect may be disturbing, and how it is possible to neutralize such a disturbing directional effect.

The directional effect of loud speakers

The appearance of a directional effect in sound radiation means that the distribution of intensity of the sound waves emitted deviates from spherical symmetry. The form of the distribution of the intensity of the sound wave depends upon the shape, the position and the dimensions of the radiating body. The loud speaker of a receiving set may for our purpose be considered by approximation to be a circular vibrating membrane placed in an infinitely large baffle board. The sound waves radiated from this source are spherically symmetrical only when

---

¹) See J. de Boer, Sound Amplification, Philips techn. Rev. 3, 221, 1938, especially pages 226-227.

the dimensions of the membrane are small compared with the wave length. When this is not the case the sound is radiated mainly in a single direction, perpendicular to the radiating membrane.

For the case in which the membrane vibrates as a whole (this condition is satisfied at frequencies which are not too high), the sound distribution can be exactly calculated. It is found that the only parameter is the quotient a/λ, in which a is the radius of the membrane and λ the wave length of the sound. *Fig. 1* shows the calculated distribution of intensity for different values of the parameter a/λ. It may be seen that for

$$2\,\pi\, a/\lambda \leqslant \text{about } 2$$

the waves are practically spherically symmetrical, while for $2\,\pi\, a/\lambda \geqslant 2$ a more and more pronounced beam formation of the waves takes place. With an ordinary radio loud speaker the vibrating surface (the cone) has a radius a = 10 to 12 cm. The limiting value of the parameter mentioned corresponds in this case to a wave length of about 35 cm, *i.e.* a frequency of 1 000 c/s. Tones of lower frequency are radiated by the loud speaker uniformly in all directions, tones of higher frequencies are, however, radiated mainly in the direction of the axis of the cone [2]).

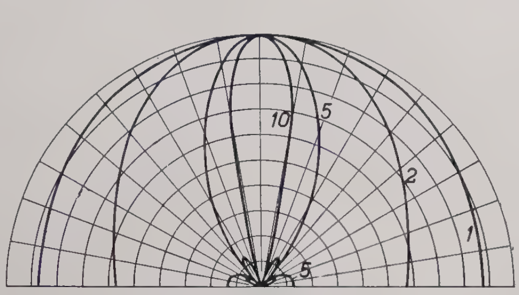


Fig. 1. Calculated directional distribution of the intensity of sound waves generated by a circular membrane vibrating as a whole in an infinitely large baffle board. The distribution is determined by a single parameter a/λ (a = radius of the membrane, λ = wave length), whose value multiplied by 2π is indicated for each curve.

This quite universal phenomenon of sound radiation, that the low tones lack a tendency to form a beam, while the high tones show such a tendency, makes itself felt as a difficulty not only when the directional effect is deliberately sought, but also when it is undesired. For the case mentioned in the introduction, where a directional effect of the loud speakers was desired for the purpose of avoiding reverberation in a hall, it is quite difficult to obtain a satisfactory beam formation of the low tones. Without special precautions the result may be that the non-directed part of the sound still causes a disturbing reverberation. On the other hand in the case where a directional effect is not desired, as in the living room of a private house, the problem is to avoid beam formation especially of the high tones. Such beam formation by the high tones has as result that the quality of the sound radiated to the sides becomes too dull and the sound directly in front of the apparatus too sharp, and that the latter sound suffers relatively more from background noise and interferences. The contribution of these extra sounds is namely the greatest at high frequencies.

The neutralization of the directional effect

How can beam formation with the high tones be avoided? [3]) One possibility would be the reduction in size of the radiating surface, which would make the limiting frequency for the occurrence of the directional effect ($2\,\pi\, a/\lambda = 2$) higher. However, in order to obtain the desired volume of sound, even in the lower tones, with a smaller loud speaker, the membrane must be given very great amplitudes at low frequencies, which leads to distortion.

A very satisfactory solution of this problem of neutralizing the beam formation is obtained by placing in the path of the sound waves emitted a body which serves to scatter the waves. The effect of such a sound diffuser is illustrated in *fig. 2*, which represents tests carried out with a ripple tank [4]). Figs. 2*a* and *b* show that with long wave lengths the "radiation" is spherical, and with short wave lengths directed. In fig. 2*c* two "sound diffusers" have been introduced into the path of the directed radiation, and it may be seen that instead of directed waves practically spherically symmetrical waves are again radiated.

It is easily understood that the dimensions of the scattering body must have a definite relation to the wave length λ of the sound to be scattered. If the dimensions are very small with respect to λ, the body has no effect on the propagation of the waves; if the dimensions are very large with respect to λ, a directional reflection of the waves occurs, so that the direction of the radiation is changed while the beam form is retained. The case in which a sphere is placed in the path of the waves has been dealt with by Stenzel [5]), who calculated the intensity of the scattered sound as a function of the radius b of the sphere and the wave length λ. Again the form of this function is found to be determined by a single parameter, namely b/λ. In *fig. 3* the results of the calculations are given for different values of the parameter. In practical cases the scattering which corresponds to the curve for $2\pi\ b/\lambda = 2$ is sufficient. If for the frequency region from 1 000 to about 4 000 c/s for example one desires to obtain an approximately uniform scattering by means of a single scattering body, the dimensions of that body will have to be chosen to correspond to an average frequency, in this case therefore about 2 000 c/s. A sphere with the radius $b = 6$ cm may then be used as sound diffuser. Since this dimension is of the same order of magnitude as that of ordinary loud speakers, all the sound from a loud speaker could be adequately scattered with one sphere.

---

[2]) This is also true for still higher frequencies, although the curves of fig. 1 cannot be directly applied in that case since the membrane then does not vibrate as a whole.

[3]) In the previously mentioned opposite case, where it was difficult to obtain beam formation of the low tones, a solution can be found in the suppression of the waves having the undesired form of propagation (frequencies below 300 cycles); the intelligibility is in this case only slightly effected. In our case where it is the high tones (above 1 000 cycles) which have the unfavourable propagation form, this method cannot of course be considered, since these tones are essential for good reproduction.

[4]) Ripple tank: a tank filled with water in which waves are generated. The propagation, reflection etc. of these waves can thus be studied. Use is often made of this aid in acoustical experiments; see for example R. Vermeulen and J. de Boer, Philips techn. Rev. 1, 46, 1936, fig. 9.

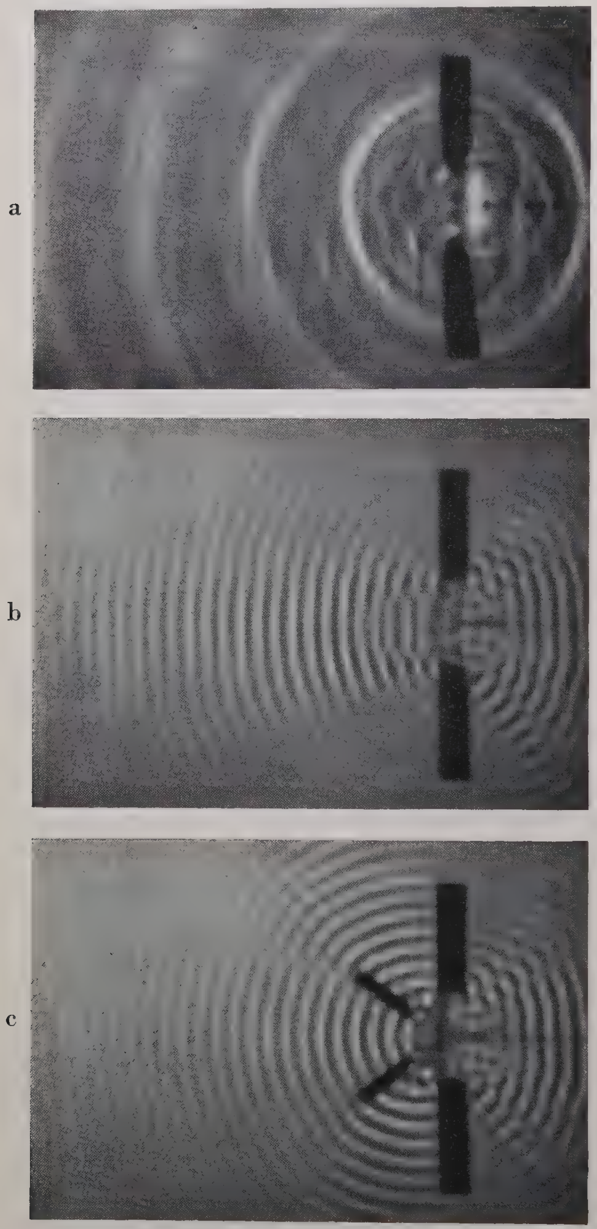


Fig. 2. Experiments with a ripple tank to illustrate the occurrence of a directional effect at high frequencies and the neutralization of this effect by means of sound diffusers.
a) The relation between "source of sound" and wave length is the same as in a loud speaker emitting a tone of 1 000 c/s; the sound intensity is the same in all directions.
b) The equivalent frequency is in this case 7 000 c/s instead of 1 000; the sound forms a beam in a single direction.
c) Like b); the beam formation is neutralized by two sound diffusers.

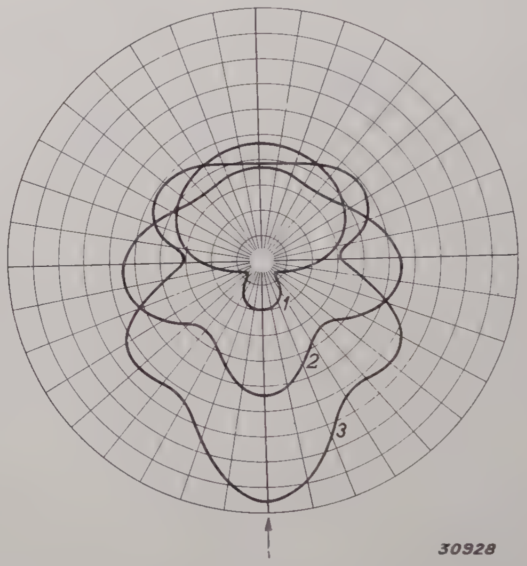


Fig. 3. Directional distribution of the sound pressure (measured at the surface of the sphere) of the wave scattered by a sphere, according to Stenzel. The sound pressure (measured at the sphere) of the plane wave incident on the direction of the arrow is set equal to unity. The scattering is determined by the parameter b/λ, whose value multiplied by 2π is indicated for each curve. At $2\pi\ b/\lambda = 2$ good scattering is obtained, at $2\pi\ b/\lambda = 3$ strong reflection already takes place.

Practical construction of sound diffusers

For structural reasons a sphere is not very suitable for use as sound diffuser in a loud speaker. If a truncated cone is used instead of a sphere the construction is very simple. This shape is used in most of the Philips loud speakers (see *fig. 4*). The best form for the cone has been determined by a large number of experiments. In *figs. 4a-d* the results of some of the measurements are given. These measurements refer to a radio loud speaker cone with an apex angle of 104°, a depth of 6.4 cm and a radius of 10 cm. Scattering cones with an apex angle of 50° and an altitude of 6 cm (they do not extend outside of the loud speaker cone) are already found to give an appreciable result. With a larger apex angle (larger area of base) there is the chance that the sound will be decreased too much directly in front of the apparatus. The scattering becomes appreciably better, however, when the

---

[5]) H. Stenzel, El. Nach. Techn. **15**, 71, 1938.

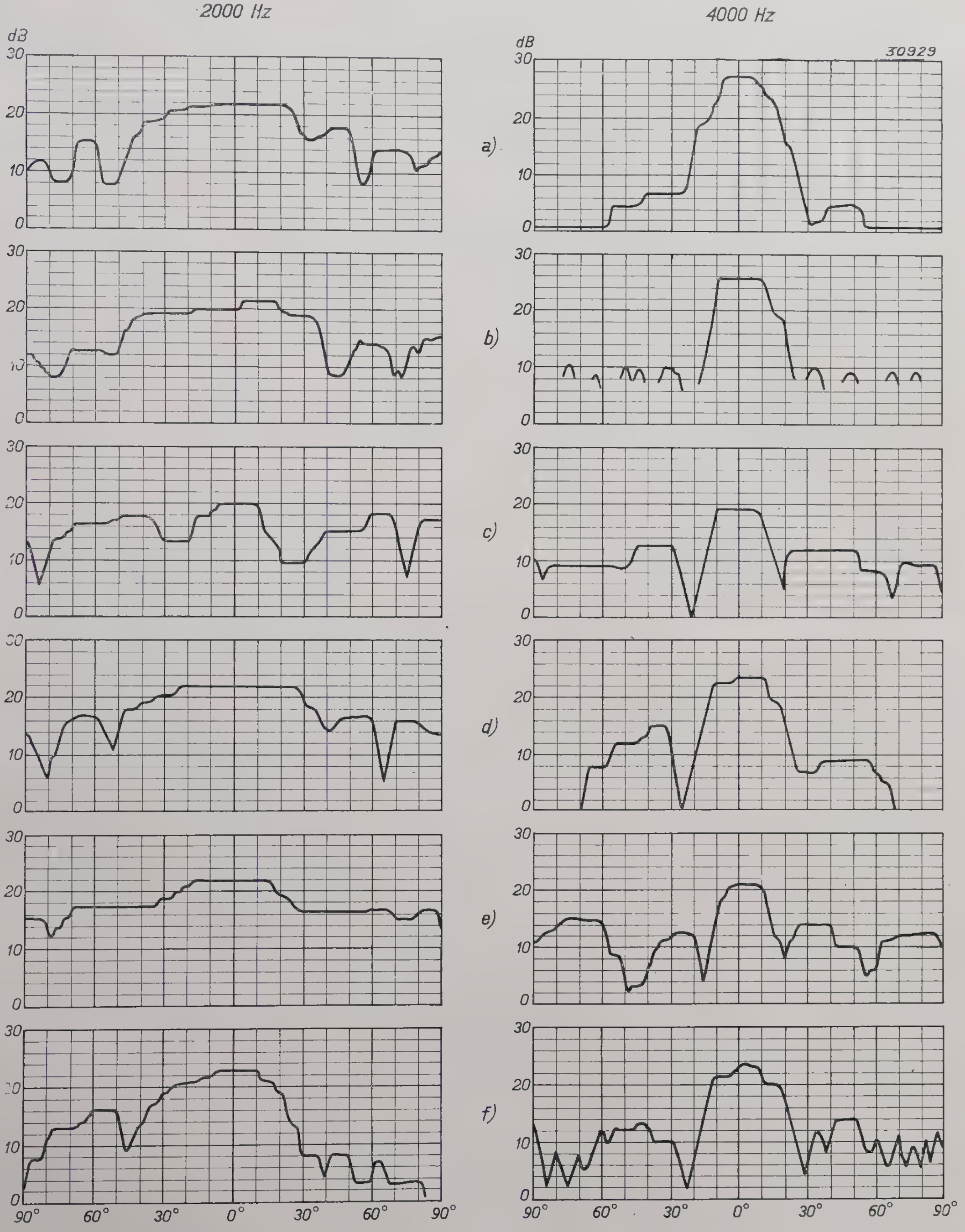


Fig. 4. Measured directional distribution of the sound intensity of a loud speaker; the intensities are measured in decibels. The recordings on the left were made at 2 000 c/s, those on the right at 4 000 c/s. The sharp minima which sometimes occur at certain angles may be ascribed to interferences which are due to the fact that at these high frequencies the membrane no longer vibrates as a whole. The measurements were made in the open air. When the loud speaker is situated in a room of a private house the minima are not noticeable, since the sound reflected from the walls is added to the direct sound.

a) Directional distribution without diffuser.
b) Scattering cone with apex angle 20°, 14 cm long.
c) Scattering cone with apex angle 50°, 14 cm long.
d) Scattering cone with apex angle 50°, 6 cm long.
e) Scattering partitions at about 50°, 14 cm long.
f) Scattering partitions at about 50°, 6 cm long.

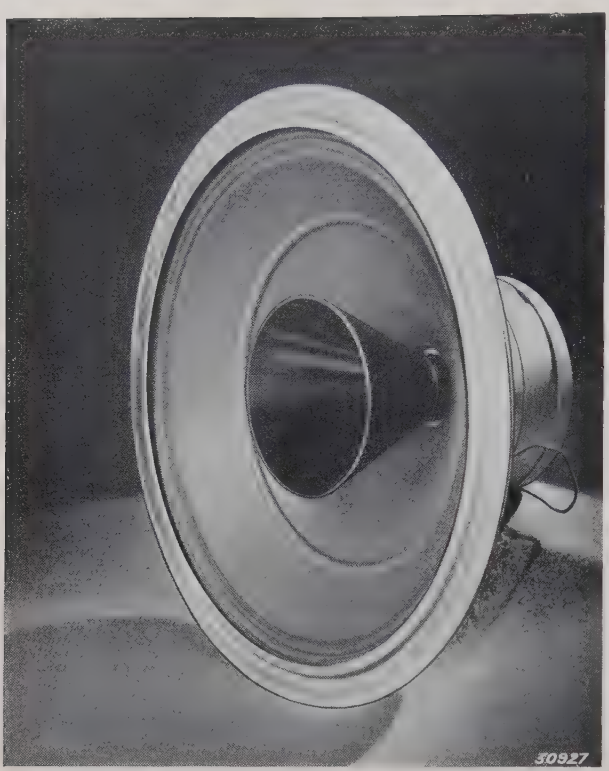


Fig. 5. Loud speaker with conical sound diffusers.

scattering cone extends farther out of the loud speaker cone (8 cm for instance).

In the construction of loud speakers for radio sets account must be taken of the necessity of housing them in a cabinet which must satisfy certain aesthetic requirements. Because of the shallowness of the space available for building in the loud speaker a scattering cone which extended very far out of the loud speaker cone would form an almost insurmountable obstacle in this respect. For this reason in the Philips loud speakers, in the cases where an improvement on the scattering obtained by means of a small cone seemed desirable, a more intense scattering has been achieved by means of two vertical partitions placed symmetrically in front of the loud speaker cone. In this case also the most suitable dimensions and position were determined experimentally. In fig. *5e-f* results of several of these measurements are given. *Fig. 6* is a photograph of a loud speaker with partitions. The partitions can be incorporated into the design of the radio cabinet in a satisfactory manner.

While the form of the distribution of the intensity of the sound wave obtained when a cone is used as sound diffuser is rotationally symmetrical to the axis of the loud speaker, the sound is spread by the vertical partitions only in one horizontal plane. For use in private homes this is no objection since in this case the heads of all the listeners are at about the same height as the loud speaker.

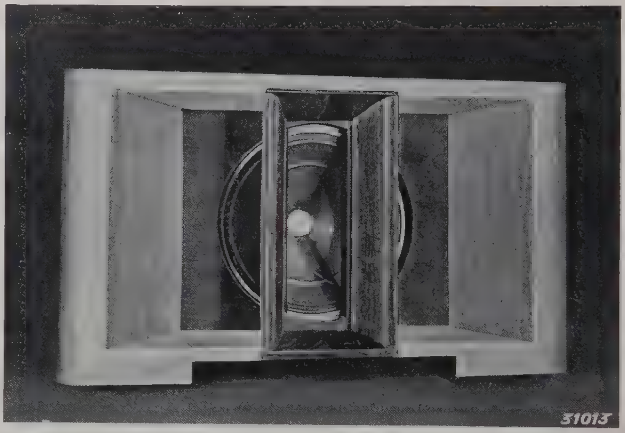


Fig. 6. Loud speaker of the receiving set 850a, with partitions in front of the loud speaker cone as sound diffuser.

THE SIGNIFICANCE OF A CONSTANT PEAK TIME IN PHOTO FLASH BULBS

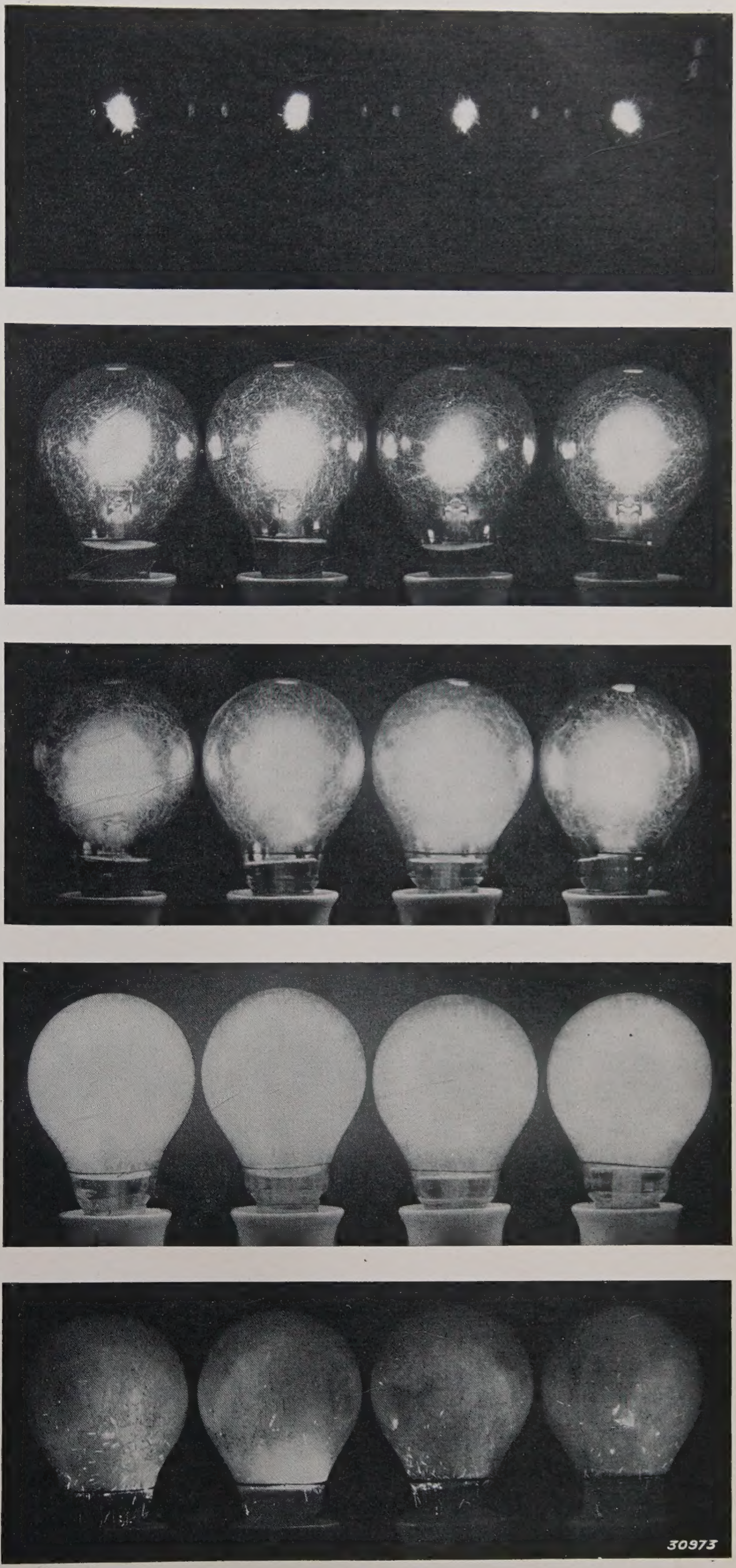
by J. A. M. van LIEMPT and P. LEYDENS. **771.448.1**

In a previous article in this periodical [1]) it was explained that certain advantages are offered in photography by flash-light, when the flash-light and the shutter of the camera can be operated simultaneously by means of a synchronizer. The latter is an apparatus which is fixed to the camera and provides that the shutter is operated at a definite (preferably determinable) moment after the ignition of the photo flash bulb. By using a synchronizer it is for example possible to make instantaneous exposures with exposure times shorter than the flash time of the flash bulb.

In the above application of the synchronizer it is of course dsirable to have the exposure take place at the moment when the flash-light is at its greatest intensity. Since the difference in time between the switching on of the flash-light and the opening of the shutter is fixed by the adjustment

---

[1]) Philips techn. Rev. **2**, 334, 1937.



Phase 1: Beginning of ignition.

Phase 2: 0.01 sec after beginning of ignition. The light zone grows from within toward the outside.

Phase 3: 0.02 sec after beginning of ignition. The light zone fills almost the entire bulb. At the wall, however, there is still a certain amount of unburned aluminium-magnesium wire.

Phase 4: 0.025 sec after beginning of ignition. The light zone has reached the wall. This is approximately the moment of maximum light development.

Phase 5: 0.055 sec after beginning of ignition.

Fig. 1. Each of the five photographs shows four "Photoflux" photo flash bulbs, type II, which were ignited simultaneously and photographed after a definite time with an exposure of 1/200 sec. The photographs show that the combustion process in all the bulbs progresses at practically the same rate.

of the synchronizer [2]) the so-called peak time, *i.e.* the time which elapses between switching on of the flash-light and its maximum light development, must be constant [3]).

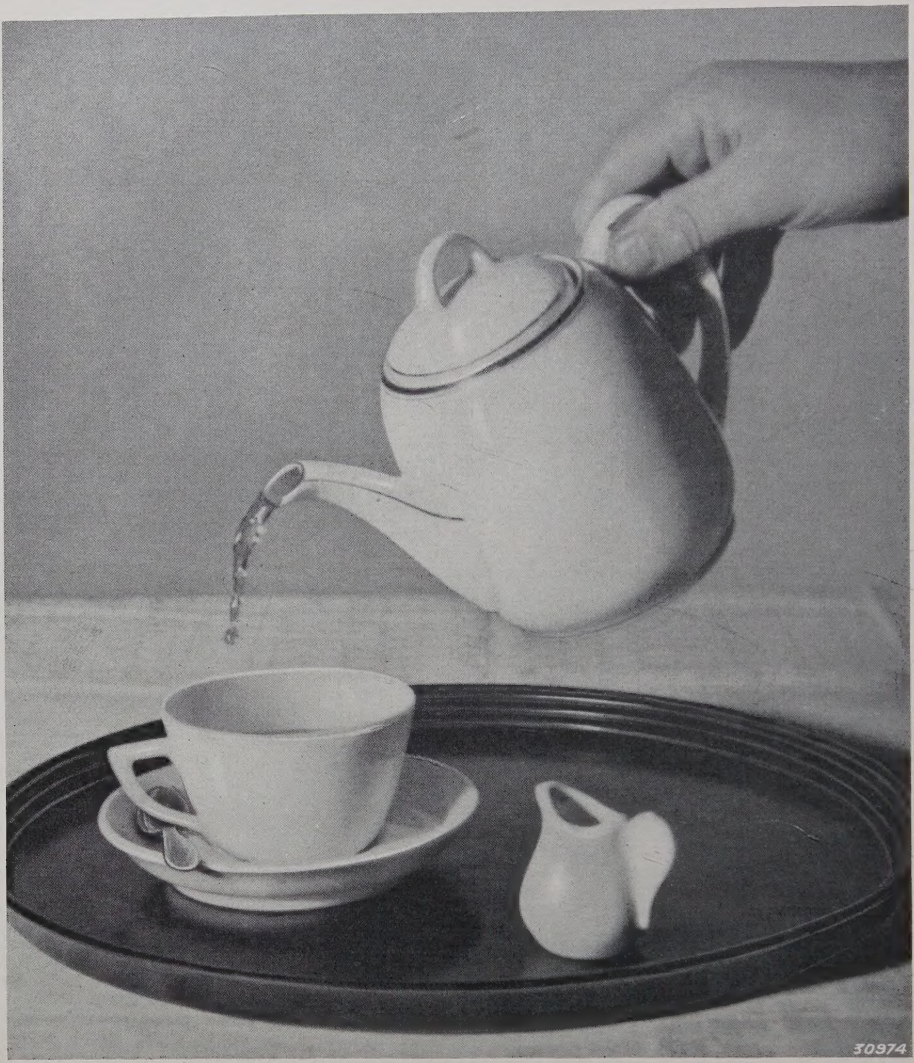


Fig. 2. Stream from the spout of a teapot upon pouring out a cup of tea at the moment when the stream of tea has not yet reached the cup.
Data:

Light source: 1 "Photoflux" type II;
Distance source to object: 1.2 m;
Diaphragm: F/11
Exposure time: $^1/_{1\,000}$ sec, focal plane shutter
Material: panchromatic $\frac{21^\circ}{10}$ DIN

In order to study the constancy of the process of combustion in its various stages, and therefore the constancy of the peak time, the following test was carried out. A number of flash bulbs, connected in parallel were simultaneously iginited by means of the 4 volt battery of an electric torch. This combination of bulbs (as subject) was photographed with an iris shutter set at $^1/_{200}$ sec. By means of an adjustable synchronizer different values were chosen for the difference in time between the ignition of the bulb and the opening of the shutter.

Fig. 1 is a series of photographs obtained in this way, in each case with four "Photoflux" flash bulbs, type II. It is clear that the different lamps behave quite similarly in all stages of the process of combustion.

---

[2]) On the subject of setting a synchronizer for operating a Compur shutter see Philips techn. Rev. **2**, 334, 1937. A method of adjustment which can be used with focal plane shutters is described in the book; Photografie bij kunstlicht, by J. A. M. van Liempt and P. Leydens, publisher N. V. Lecturius, which will appear shortly.

[3]) Since shutter, synchronizer and the torch battery with which the synchronizer is set in action are subject to certain variations, it is desirable that the maximum of the light-time curve of the flash-light should not be too narrow. This curve in the case of the "Photoflux" satisfies the requirements and is shown in Philips techn. Rev. **2**, 334, 1937, fig. 6.

Thanks to the constancy of the bulb, which has made it possible to couple shutter and bulb effectively, it is possible to make any desired instantaneous exposures by flash-light with short exposure times such as were previously only possible by artificial light with an ultra fast film camera. This will be clear when it is kept in mind that a "Photoflux" type II develops a light flux of more than 2 million lumens at the moment of greatest intensity. Upon use of a reflector the intensity of illumination at a distance of 2 m corresponds approximately to that of bright sunlight in the summer. *Figs. 2 and 3* are two examples of subjects which can only be photographed with extremely short exposure times. As may be seen from the text under the figures, with an exposure time of $^1/_{1000}$ sec, there is even sufficient light to make it possible to use a relatively small diaphragm, which increases the depth of focus in the pictures.

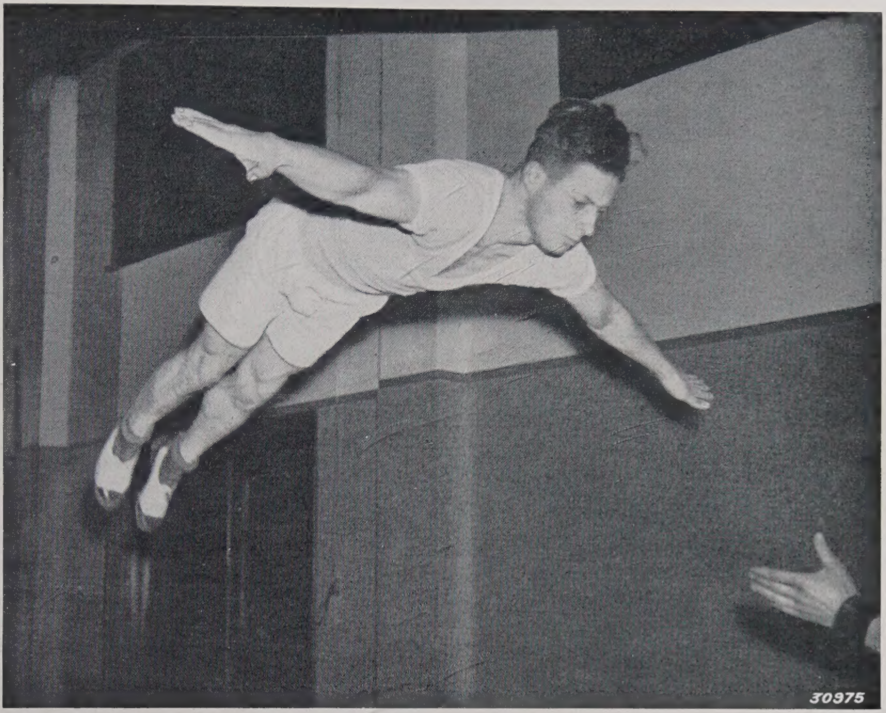


Fig. 3. Dive photographed unter the following conditions:
Light source: 1 "Photoflux", type II;
Distance source to object: 4 m;
Diaphragm: F/6.3;
Exposure time: $^1/_{500}$ sec. Compur shutter;
Material: panchromatic $\frac{21^\circ}{10}$ DIN.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

1364*): R. Houwink and Ph. N. Heinze: Prüfung von Kunstharzen mit dem Plastometer (Kunststoffe **28**, 283-287, Nov. 1938)

For determining the quality of resins, especially of hardening artificial resins, it is very important to know the hardness or the softening point and the speed of hardening. In this article several instruments are described for the measurement of these properties, while several results obtained with the instruments are discussed.

1365: C. J. Bakker and Balth. van der Pol: Report on spontaneous fluctuations of current and potential (C.R. Union Rad.-sci. int., Venise, **5**, 217-227, 1938).

In this report to the congress of the Union Radio-scientifique internationale held in Venice in 1938, the causes were discussed of spontaneous fluctuations of current and potential. They are the following:

1) the heat motion of the electrons in the electrical circuits and
2) the irregular transition of the electrons in an evacuated tube. As causes of the irregular transition of electrons were mentioned: shot effect, secondary emission and the distribution of the electrical current over the different electrodes.

1366*: F. Coeterier: Demonstration of the principle of the infra-red telescope (Ned. T. Natuurk. **5**, 216-218, Sept. 1938).

1367: A. C. van Dorsten: Cascade generators for high direct voltages (Ned. T. Natuurk. **5**, 218-220, Sept. 1938).

1368*: W. Elenbaas: High-pressure mercury discharges (Ned. T. Natuurk. **5**, 221-222, Sept. 1938).

1369*: P. H. J. A. Kleynen: Model for the investigation of the motion of electrons in two-dimensional electrostatic fields (Ned. T. Natuurk. **5**, 222-224, Sept. 1938).

1370*): J. F. Schouten: The use of sound film as diffraction grating for light (Ned. T. Natuurk. **5**, 224-228, Sept. 1938).

These five short contributions give a description of a series of demonstrations which were given before a meeting of the Netherlands Physical Society on June 18, 1938 in the Philips Laboratory. For **1367** we may refer the reader to: Philips techn. Rev. **1**, 6, 1936 and **2**, 161, 1937, for **1369***) to Philips techn. Rev. **2**. 338, 1937 and for **1370***) to Philips Rev. **3**, 298, 1938.

1371: A. Bouwers: Die Technik der Neutronenerzeugung und der Erzeugung künstlicher Radioaktivität (Strahlentherapie, **63**, 537-544, Nov. 1938).

In this article a survey is given of the different methods of producing neutrons (cf. also: Philips Techn. Rev. **3**, 339, 1938), and various apparatus are described for the acceleration of charged particles. The excitation of radioactivity by bombardment with neutrons is discussed briefly, as well as the measures necessary for protection against high tension, X-rays and neutrons.

1372: J. F. Schouten: The perception of subjective tones (Proc. kon. Ned. Akad. Wet. A'dam **41**, 1086-1093, Dec. 1938).

When a purely sinusoidal tone strikes the ear, one perceives, besides the main tone, several overtones, due to non-linear effects in the ear. When a complex sound is heard from which the actual main tone has been removed so that the sound really consists only of overtones, then due to sound distortion in the ear the main tone may also be perceived, namely as the difference tone of the harmonics. With the help of artificially produced sound, the author has investigated the factors which determine the pitch of the tone perceived. This pitch is by no means determined by the lowest tone which occurs in the Fourier analysis of the sound striking the ear or excited in the ear by distortion. Even when the main tone is entirely absent in the ear, a pitch is assigned to the tone which corresponds to that of the missing main tone. This seems to indicate that the ear is actually able to observe the fundamental period of a complex sound and in this way to reach a perception of the pitch.

---

*) An adequate number of reprints for the purpose of distribution is not available of the publications marked with an asterisk. Reprints of other publications may be obtained on application to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.